National Aeronautics and Space Administration

Navigator Program
Jet Propulsion Laboratory
California Institute of Technology

Date November 30, 2001

Advanced Cryocooler Technology Development Program
Technology Announcement

Notice of Intent to Propose Due: January 11, 2002
Proposal Due: January 25, 2002

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Advanced Cryocooler Technology Development Program
TECHNOLOGY ANNOUNCEMENT

The Navigator Program is a NASA Office of Space Science (OSS) program, managed by the Jet Propulsion Laboratory (JPL), to study the origin and development of galaxies, stars, planets, and the chemical conditions necessary to support life. This Advanced Cryocooler Technology Development Program (ACTDP) Technology Announcement (TA) solicits proposals for cryocooler technologies that will enable long life OSS Astronomy and Physics Division missions. This TA is restricted to U.S. organizations including industry, universities, nonprofit organizations, Federally Funded Research and Development Centers (FFRDC), NASA Centers, and other government agencies.

The primary users of ACTDP technologies will be NASA's "Next Generation Space Telescope (NGST)", Constellation-X (Con-X), and Terrestrial Planet Finder (TPF) missions. The technology performance needs and demonstration requirements for an ACTDP cryocooler are described in APPENDIX A of this TA. General instructions for responding to this TA are given in APPENDIX B. Specific instructions for proposal preparation are given in APPENDIX C.

The evaluation of technology proposals will be done using a technical peer review process as described in APPENDIX D. The selection criteria for evaluation and their relative importance summarized below are described in APPENDIX C.2 including details of the evaluation factors.

- Technical merit and benefits to future astrophysics missions (30%)
- Technology maturation (30%)
- Management and implementation approach (30%)
- Capabilities of the provider organization (10%)

The technology selection process will occur in two steps. Selected proposers will initially participate in a six-month Technology Concept Definition Study Phase ("Study Phase"). In the Study Phase, each prospective technology provider will be required to produce a detailed preliminary design for the proposed cryocooler (refer to APPENDIX E), documented in a final study report which will be evaluated by NASA and serve as the primary basis for down-selection to the Demonstration Phase. Only the technology providers selected for the Study Phase will be considered for the Demonstration Phase. Therefore, NASA plans to solicit, negotiate, and award technology provider contracts (or other agreements) through completion of the Demonstration Phase without further competition.

The Study Phase will involve developing a preliminary design for the proposed cryocooler. The Demonstration Phase will involve final design, development, test and evaluation, and delivery of an Engineering Model cryocooler system. A cryocooler concept appropriate for the ACTDP should be mature enough to demonstrate its capabilities and potential performance in a relevant environment within three to four years from the start of the Study Phase.

Approximately four (4) technology concept proposals may be selected for the Study Phase. The ACTDP anticipates Study Phase contract (or other agreement) values in the range of $50,000.00 to $500,000.00 each. The total funding planned for all Study Phase activities is approximately $2 million. At the end of the Study Phase, NASA plans to down-select two to three (2-3) concepts for the Demonstration Phase. The total funding available for all Demonstration Phase activities is anticipated to be approximately $12 million. In all cases, NASA's obligation to fund contract (or other agreement) awards is contingent upon the availability of funds and the receipt of proposals that NASA determines are acceptable for award under this TA.

NASA will reject any proposals received from government, national laboratory, or FFRDCs that are substantially the same as an industry or university proposal. Accordingly, the government, national laboratory, or FFRDC proposal will not be evaluated and will be returned to the originator.

The following information applies to this TA:

Industry Briefing:	November 15, 2001
Date of ACTDP TA issue:	November 30, 2001
Notice of Intent to Propose Due:	January 11, 2002
Proposal Due Date:	January 25, 2002 at 3:00 p.m. PDT
Study Phase Start Date (approximately):	April 1, 2002
Proposal Page Limit:	25 Pages
Required Number of Proposals:	Submit twenty (20) copies and (1) PC readable electronic copy .pdf file format on 3.5-inch disk or ZIP disk, or CD-ROM.
Mailing address:	Jet Propulsion Laboratory 4800 Oak Grove Drive, Mail Stop 190-220 Pasadena, CA 91109-8099 Attn: William D. Kert
Address for hand delivery:	Jet Propulsion Laboratory Visitor Control Center Building 249 4800 Oak Grove Drive Pasadena, CA 91109-8099 Attn: William D. Kert
Initiation of funding:	With contract (agreement) award
General Point of Contact:	Mr. William D. Kert Jet Propulsion Laboratory 4800 Oak Grove Drive, M/S 190-220 Pasadena, California 91109-8099 e-mail: william.d.kert@jpl.nasa.gov Telephone: (818) 354-2992

If you have any questions about this TA, please contact Mr. William D. Kert.
Your interest in submitting a proposal in response to the ACTDP TA is appreciated.

Original signed by

Michael Devirian,
Manager, Navigator Program

APPENDIX A

ACTDP CRYOCOOLER PERFORMANCE AND TECHNOLOGY DEMONSTRATION REQUIREMENTS

Note: NASA reserves the right to change this APPENDIX, as needed, at the commencement of Demonstration Phase activities.

A.1 INTRODUCTION

NASA is planning future large space observatories to investigate the structure and evolution of the universe and search for the origins of galaxies, stars, planets and, ultimately, life. These investigations will be part of the Astronomical Search for Origins and Planetary Systems (ASO) theme and the Structure and Evolution of the Universe (SEU) theme in the Space Science Enterprise. Observations will span the electromagnetic spectrum from X-rays to the far infrared. A key technology need common to many observatory concepts is the capability to reliably cool detectors and associated components to temperatures around 6K for extended mission durations up to ten years. The primary user missions for this technology include the Terrestrial Planet Finder (TPF), Constellation-X (Con-X) and the Next Generation Space Telescope (NGST). The ACTDP is seeking those technologies that can demonstrate a cryocooler design capable of realistically completing flight unit development and delivery in the 2006 to 2007 time frame.

A.2 BACKGROUND / MISSION APPLICATIONS INFORMATION

Information on future NASA Office of Space Science (OSS) Astronomy and Physics Division missions may be found at the URL: http://spacescience.nasa.gov/

The TPF mission will search for earth-like planets around nearby stars, provide the first direct images of such planets and perform low resolution spectroscopic studies of the planetary atmospheres. In addition, TPF will support general astrophysics studies by providing unprecedented imaging capability. Several TPF system architecture concepts are currently under study. These include visible coronagraphs and infrared nulling interferometers, as well as several other related concepts. For systems observing in the infrared, from ~3-30 microns, cooling the detectors to around 6K will be required over the mission life time of 5 to 10 years. Additional information on TPF can be found at: http://tpf.jpl.nasa.gov/

The Con-X mission will enable the observation of black holes and test the General Theory of Relativity with a group of four spacecraft, each carrying two X-ray telescopes. The spacecraft will be launched in pairs, with roughly a year between launches, and four years of operation as a group. A multi-stage cooling system will be used to maintain microcalorimeters in the Soft X-ray Telescope at 50mK, enabling very high spectral resolution from 0.3 - 10 keV. A 6K cryocooler derived from the ACTDP will be used as the upper stage(s) in this system. Information on Con-X can be found at: http://conxproject.gsfc.nasa.gov/

NGST will examine our universe in wavelengths between 0.6 and 28 microns during a mission lasting up to ten years. The mid-infrared instrument for NGST will likely use detectors operating at temperatures as low as 6K. A stored cryogen system is included in the baseline system for this instrument. However, the ACTDP cryocooler technology may offer some tangible benefits. NGST will be flown prior to TPF and the two are anticipated to have similar mid-infrared instrument requirements. Background information on the NGST observatory is available at http://ngst.gsfc.nasa.gov/. Relevant NGST documents there include:

"NGST Monograph Series #1: Yardstick Mission Definition"
    http://www.ngst.nasa.gov/cgi-bin/pubdownload?Id=597
"A Report of the NGST Mid-IR Camera/Spectrograph Sub-Committee"
    http://www.ngst.nasa.gov/public/unconfigured/doc_0576/rev_01/Mir_sub.pdf
"NGST Integrated Science Instrument Module" (SPIE Manuscript April 2000)
    http://www.ngst.nasa.gov/cgi-bin/pubdownload?Id=636
"NGST Integrated Science Instrument Module" (SPIE Presentation: March 2000)
    http://www.ngst.nasa.gov/cgi-bin/pubdownload?Id=626
"Technology Development Requirements and Goals for the NGST Detectors," (October 2001)
    http://www.ngst.nasa.gov/cgi-bin/pubdownload?Id=641

A.3 ACTDP SCOPE

The ACTDP will be a two phase program. The main deliverables for each phase are as follows:

1. Study Phase
    a. A three volume Study Phase Final Report that describes:
        - The preliminary design of an Engineering Model (EM) cryocooler system (EM mechanical cryocooler and brassboard electronics)
        - The Demonstration Phase Technical Plan for developing and demonstrating the EM cryocooler system, including options for:
            i. Delivering a second "build-to-print" EM cryocooler system
            ii. Developing and demonstrating a set of EM electronics
        - The management and cost plan for implementing the Demonstration Phase Technical Plan
2. Demonstration Phase
    a. The EM cryocooler system (EM mechanical cryocooler and brassboard electronics) and associated ground support equipment
    b. A plan for developing / delivering a flight model cryocooler system

Details on the complete scope of work and deliverables for each phase are in later appendices.

A.4 CRYOCOOLER TECHNOLOGY DEMONSTRATION REQUIREMENTS

The ACTDP participants will demonstrate technologies suitable for application to the missions cited above. The primary deliverable will be an Engineering Model (EM) Cryocooler system from each technology provider selected. An EM Cryocooler system is expected to consist of a mechanical subsystem and an electronic subsystem, which have different ACTDP requirements as summarized below.

The EM mechanical cryocooler subsystem shall be fully flight-like in form, fit and function, and allow assessment of its design to meet all key thermal, structural and reliability/lifetime performance requirements in vibration and thermal-vacuum test environments. It shall be capable of providing the required cooling system performance over the full range of interface temperatures, and be suitable for multi-year life-testing. It should also allow assessment of its susceptibility to self-contamination over time. The EM mechanical cryocooler need not have negotiated flight interfaces, formal flight drawings, or flight-approved materials, electronic parts, or fasteners except where they are critical to performance.

Brassboard electronics for the EM mechanical cryocooler shall be fully flight-like in function (e.g. power and control functionality), but do not require flight-like form, fit, or full radiation hard nor high reliability parts, or the ability to be tested in vibration or thermal-vacuum environments. The brassboard electronics for the EM mechanical cryocooler shall be rack mounted for operation in a lab environment. They shall be capable of operating the EM mechanical cryocooler subsystem over its full range of capabilities to allow assessment of the cryocooler's overall design with respect to key efficiency, control, and refrigeration performance requirements. The digital functionality of the brassboard electronics may be simulated with PC-based hardware and software. The brassboard electronics are not required to have flight packaging, flight-approved electronic parts, or flight software, except where they are critical to performance, and need not address flight structural, thermal, or space radiation issues.

If the option to provide EM electronics for the EM mechanical cryocooler is exercised, then the EM electronics shall fully demonstrate the form, fit, and function of flight model electronics, to allow assessment of the ability of the circuit and mechanical design to meet key electrical, thermal, structural, and EMI performance requirements over the Allowable Flight Operating temperature range. The EM electronics circuit and packaging design shall be based on flight-worthy radiation hard, high reliability parts and processes that are compatible with the specified flight operating temperature, radiation, and SEE environments. However, the fabricated EM electronics unit need not have formal flight drawings, or flight-approved radiation hard, high reliability materials, electronic parts, or fasteners except where they are critical to performance. The EM electronic unit shall be suitable for powering the EM Mechanical cryocooler system during multi-year life-testing.

Flight Model (FM) hardware development and delivery is <u>not</u> within the scope of the ACTDP. However, ACTDP participants will be asked to develop the requirements for, and design of FM systems. FM systems (mechanical or electronic) shall be fully flight-like in form, fit and function, meeting all interface and documentation requirements for flight application, and be capable of successfully completing space qualification testing unless otherwise stated.

A.5 ATTACHMENTS

The following attachment to APPENDIX A provides detailed specifications for an ACTDP Cryocooler.

a. ACTDP Cryocooler Detail Specification

EQUIPMENT SPECIFICATION

ACTDP CRYOCOOLER DETAIL SPECIFICATION

Version 1.05

November 28, 2001

DOCUMENT CHANGE RECORD

Revision Status			
Revision	Date	Approval	Paragraphs Affected
Draft 1.0	11/7/01	RK	Initial copy released for bidder comment
Version 1.05	11/28/01	RK	3.2.2.5.4, 3.2.4.3.1, 3.3.1.2.6, 3.3.1.3.1, 3.3.3.8, 4.4.8

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1. SCOPE

1.1 CONTENT

This specification defines the requirements for the design, development, and verification of an Advanced Cryocooler Technology Development Program (ACTDP) Cryocooler. **The requirements are representative of those for a flight-model cryocooler and are intended to guide the ACTDP cryocooler design effort. In many cases, the EM and Brassboard hardware deliverables need only meet a subset of these requirements as defined in the Product Verification Matrix presented in Table 4.3-1.**

1.1.1 **Conflicting Requirements.** Conflicts arising between the requirements of this specification and the requirements of any document referenced herein shall be referred to the ACTDP Manager for resolution.

1.2 PURPOSE

The cryocooler described in this specification is targeted at providing cryogenic cooling for a class of NASA missions including the Terrestrial Planet Finder (TPF),Constellation-X (ConX), and Next Generation Space Telescope (NGST).

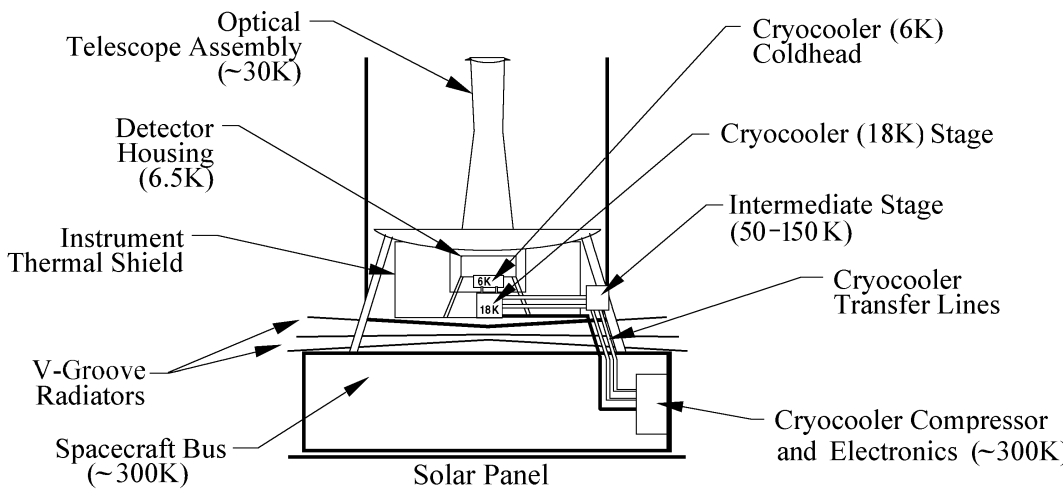

Figure 1.3.1-1. Schematic illustration of example TPF cryocooler application.

1.3 DESCRIPTION

1.3.1 **Overall Cryocooler Application.** The class of applications being addressed by the ACTDP cryocooler is schematically illustrated in Fig. 1.3.1-1. In these applications the cryocooler load is a 6.5 K detector mounted remotely in a cryogenically cooled instrument that is thermally isolated from, and mounted onto, a room-temperature spacecraft. The cryocooler system is to provide approximately 7.5 mW of cooling at 6 K to cool the instrument detector, plus approximately 250 mW of cooling at 18 K to cool the detector housing and thermal shields. It is likely that the cryocooler will want to make use of an intermediate-temperature upper cryogenic stage (either active or passive) in the range of 50 to 150 K. This intermediate stage may either be provided as part of the ACTDP cryocooler, or the ACTDP cryocooler design may assume the presence of a separate spacecraft-provided intermediate stage with the cooling capability defined in 3.2.3.3.3. The overall ACTDP cryocooler consists of a mechanical cooler and a set of cooler electronics as shown in Fig. 1.3.1-2.

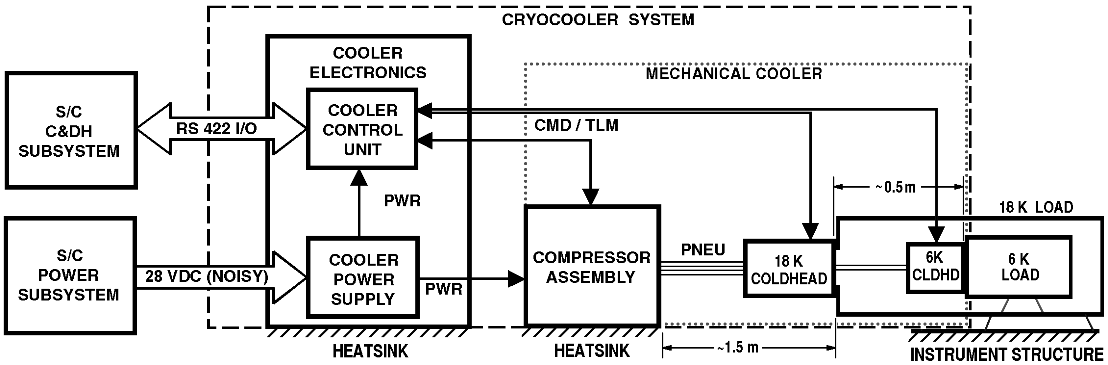

Figure 1.3.1-2. Schematic of ACTDP cryocooler elements and interfaces.

1.3.2 Mechanical Cooler. The mechanical cooler consists of a compressor assembly and a coldhead assembly. The compressor assembly and the coldhead assembly shall be physically separated as shown in Fig. 1.3.1-2 and connected only by one or more flexible gas transfer lines and electrical wiring for sensors and control.

1.3.2.1 ***Compressor Assembly.*** The compressor assembly provides the source(s) of compressed gas to the coldhead assembly. The compressor is the more massive, high-power-dissipation portion of the cryocooler and shall be structurally supported from the spacecraft primary structure and thermally controlled by the spacecraft to near room temperature.

1.3.2.2 ***Coldhead Assembly.*** The coldhead assembly provides refrigeration to the instrument cryogenic loads at both 6 K and 18 K. It will be coupled to, and may be structurally supported from, the 6K and 18K cryogenic loads. The coldhead assembly will be coupled to the compressor assembly via one or more gas transfer lines.

1.3.2.3 ***Transfer lines.*** The transfer lines provide a gas flow connection between the compressor assembly and the coldhead of the cryocooler.

1.3.2.4 ***Intermediate Temperature Stage.*** It is likely that the ACTDP cryocooler will make use of an intermediate-temperature upper cryogenic stage (either active or passive) between the room temperature compressor assembly and the 6 K and 18 K stages. This intermediate stage may either be provided by the contractor as part of the ACTDP cryocooler, or it may be assumed to be provided separately by the spacecraft/instrument payload. As an example, the intermediate stage could be an integral upper stage of the 18K cooler provided by the contractor, or it could be a spacecraft-provided passive radiator used as an upper-stage precooler by the ACTDP cryocooler.

1.3.3 Cooler Electronics. The cryocooler electronics consist of power drive electronics, to drive the compressor assembly, and cooler control electronics as shown in Fig. 1.3.1-2. The cooler power drive electronics condition the power from the 28V DC Spacecraft Noisy Bus and provide it in a form (generally AC power at some fixed frequency) to drive the compressor assembly. The cooler control electronics provide closed-loop control of various compressor and coldhead functions, monitor the status of key performance and safety parameters, and communicate with the host S/C via an RS422 serial bus. Generally the control electronics will contain both analog and digital circuitry, and supporting software. For the ACTDP flight cooler application the electronics shall be single-string, non-redundant, except in selected critical areas to be defined by the contractor to enhance reliability and meet the lifetime requirement.

2. APPLICABLE DOCUMENTS

The following documents, of the issue specified in the contractual instrument, form a part of this specification to the extent specified herein.

STANDARDS

Jet Propulsion Laboratory

JPL-STD00009	Preferred Materials, Fasteners, Processes, and Packaging and Cabling Hardware

Federal/NASA

FED-STD-209	Controlled Environment, Clean Room and Work Station Requirements
MSFC-HDBK-527	Materials Selection List for Space Hardware Systems

Military

MIL-HDBK-5E	Metallic Materials and Elements for Aerospace Vehicle Structures
MIL-STD-461C	Requirements for the Control of EMI Emissions and Susceptibility
MIL-STD-462C	Electromagnetic Interference Characteristics, Measurement of
MIL-STD-882	System Safety Requirements
MIL-STD-975H	Standard Electrical, Electronic, and Electro-mechanical Parts
MIL-STD-1246A	Product Cleanliness Levels and Contamination Control Program
MIL-STD-1472D	Human Engineering Design Criteria for Military Systems, Equipment, and Facilities
MIL-STD-1522A	Standard General Requirements for Safe Design and Operation of Pressurized Missile and Space Systems
MIL-STD-1815A	Ada Language Reference Manual

Commercial

ANSI STD X3.9	FORTRAN Programming Language Standard
ANSI STD X3/159	C Programming Language Standard
ANSI Y14.5M	Dimensioning and Tolerancing
ASTM E595-93	Standard Test Method for Total Mass Loss and Collected Volatile Condensable Materials from Outgassing in a Vacuum Environment

PUBLICATIONS

Jet Propulsion Laboratory

JPL D-8208	Spacecraft Design and Fabrication Requirements for Electronic Packaging and Cabling
JPL D-8545B	JPL Derating Guidelines

Military

EWR 127-1	Eastern and Western Range Safety Requirements

Commercial

EIA RS-422	Electrical Characteristics of Balanced Voltage Digital Interface Circuits

3. REQUIREMENTS

3.1 DEFINITIONS

3.1.1 Modes of Operation

The cryocooler shall implement various operating modes as required to interface with the S/C and instrument operating modes. Example modes include:

3.1.1.1 ***Launch/Off Mode***. In Launch/Off Mode, no primary power will be supplied to the cryocooler.

3.1.1.2 ***Standby Mode***. When power is first applied to the cryocooler it shall be in Standby Mode. The cooler digital communication and control electronics shall be on and the complete data message list shall be available. The compressor power driver and other power drivers shall be in an unpowered state. In the Standby Mode it shall be possible to upload setpoint parameters and enable other submodes such as caging and uncaging the cooler.

3.1.1.3 ***Cooldown Mode***. For some cryocoolers, special parameter settings or operating functions may be required when cooling down between the Baseline Cooldown Starting Condition (3.2.2.1.4) and the Baseline Operating Point (3.2.2.1.2). In the Cooldown Mode, the cooler will be uncaged, the control unit and compressor drive shall be fully functional, and those settings necessary for cooldown operation shall be implemented.

3.1.1.4 ***Normal Mode***. In Normal Mode the control unit shall be fully functional, and the compressor drive electronics shall be fully operational. In the Normal Mode it shall be possible to update setpoint parameters such as closed-loop coldhead temperature, closed-loop vibration control, or cooler fixed-drive level.

3.1.1.5 ***Shutdown Mode***. In Shutdown Mode, the compressor drive and any other drive power such as displacer drive shall be set to zero. Following a software-initiated shutdown, all control loops shall be disabled and returned to default values. Following entering Shutdown Mode, the cryocooler shall automatically transition to Standby Mode.

3.2 CHARACTERISTICS

3.2.1 Physical Characteristics

3.2.1.1 ***Size***. The mechanical cooler and the cooler electronics shall be as compact as possible consistent with reasonable cost, efficient and reliable assembly, and access for rework.

3.2.1.1.1 <u>18K Coldhead Separation Distance</u>. The distance between the mechanical cryocooler 25°C heat rejection interface and the 18K coldhead coldload interface shall, as a goal, be at least 1.5 m to allow the compressor/expander heat rejection to occur at the spacecraft and the 18K coldhead to be mounted to the remote 18K load. Note that, if needed, technologies such as loop heat pipes or CPLs may be used in the achievement of this separation distance.

3.2.1.1.2 <u>6K to 18K Coldhead Separation Distance</u>. The distance between the 6K coldhead coldload interface and the 18K coldhead coldload interface shall be at least 0.5 m to allow the 6K coldhead to be mounted remote from the 18K coldhead coldload interface.

3.2.1.2 ***Mass***. The mass of the cryocooler, including electronics and all intracooler cables and transfer lines, shall be as light as possible consistent with reasonable cost, and adequate structural and thermal robustness; as a goal, it shall be less than 40 kg.

3.2.2 Performance

The cryocooler shall meet all requirements specified herein throughout the operating life specified in 3.2.2.5, after exposure to the ground and space environments specified in 3.2.4.1 and 3.2.4.3, and after exposure to the launch environments specified in 3.2.4.2.

3.2.2.1 *Refrigeration Performance*

The cryocooler shall be capable of stable operation within specification over a range of applied cryogenic heat loads and interface heat rejection temperatures as described below:

3.2.2.1.1 EOL Operating Point. The EOL Operating Point is defined as the cooling capacity at the Predicted End-of-Life (EOL) Condition as defined by 3.2.2.5.4 with all heat rejection interfaces at their maximum Flight Allowable-Operating temperatures per Table 3.2.4.3-1. The cryocooler shall have a predicted EOL Operating Point of no less than 7.5 mW at 6 K on the 6K coldload interface in combination with 250 mW at 18 K on the 18K coldload interface.

3.2.2.1.2 Baseline Operating Point. The Baseline Operating Point is defined as a load of 7.5 mW at 6 K on the 6K coldload interface in combination with 250 mW at 18 K on the 18K coldload interface with all heat rejection interfaces at their Baseline temperatures per Table 3.2.4.3-1.

3.2.2.1.3 Minimum Operating Point. The Minimum Operating Point is defined as the lowest cooling condition for which full operational specifications are met. The cryocooler shall have a Minimum Operating Point no greater than 4 mW at 6 K on the 6K coldload interface in combination with 50 mW at 18 K on the 18K coldload interface with all heat rejection interfaces at their minimum Flight Allowable-Operating temperatures per Table 3.2.4.3-1.

3.2.2.1.4 Baseline Cooldown Starting Condition. The baseline cooldown starting condition is defined as all heat rejection interfaces at their baseline values per Table 3.2.4.3-1 and the coldhead assembly and the 6K and 18K cryogenic loads at equilibrium at 100 K.

3.2.2.1.5 Cooldown Time. The cryocooler shall cool down from the Baseline Cooldown Starting Condition per 3.2.2.1.4 to the Baseline Operating Point per 3.2.2.1.2 in less than 24 hours (with a goal of less than 2 hours). During cooldown, the 6K coldload interface shall have an attached thermal mass equivalent to 50 grams of copper and be loaded with an additional heat load of 7.5 mW, and the 18K coldload interface shall have an attached thermal mass equivalent to 250 grams of copper and be loaded with an additional heat load of 250 mW.

3.2.2.2 *Power Consumption*

3.2.2.2.1 Baseline Power Consumption. Baseline Power Consumption is defined as the input power to the cryocooler electronics from a 28 Vdc bus when the cooler is operating at equilibrium at the Baseline Operating Point of 3.2.2.1.2. The Baseline Power Consumption shall be minimized to the extent practical. If increased power is needed due to inclusion of the intermediate-temperature stage as part of the ACTDP cooler, this power increase should be balanced by an increase in ease of spacecraft accommodation and reduction in spacecraft-supplied cooling facilities. As a goal, the baseline power consumption should be less that 150 watts at cryocooler beginning of life.

3.2.2.2.2 EOL Power Consumption. EOL Power Consumption is defined as the predicted input power to the cryocooler electronics from a 28 Vdc bus when the cooler is in its Predicted End-of-Life (EOL) Condition as defined by 3.2.2.5.4 and is operating at equilibrium with a load of 7.5 mW at 6 K on the 6K coldload interface in combination with 250 mW at 18 K on the 18K coldload interface with all heat rejection interfaces at their maximum Flight Allowable-Operating temperatures per Table 3.2.4.3-1. As a goal, the EOL Power Consumption shall be less than 250 watts at cryocooler end-of-life (EOL).

3.2.2.3 ***Temperature Sensors and Control***. The cryocooler shall provide for measuring the coldload interface temperatures and adjusting their control setpoints as described below.

3.2.2.3.1 Temperature Sensors. The cryocooler shall provide redundant temperature sensors mounted on both the 6K and 18K coldhead coldload interfaces for monitoring and control.

3.2.2.3.1.1 6K Temperature Sensors. The 6K coldhead temperature sensors and their readout electronics shall be capable of measuring the 6K coldhead interface temperature in the range from 4 K to 373 K and maintain an accuracy of ±0.01 K over the mission duration for the temperature range 4 K to 15 K, and ±1 K for the temperature range 15 K to 373 K.

3.2.2.3.1.2 18K Temperature Sensors. The 18K coldhead temperature sensors and their readout electronics shall be capable of measuring the 18K coldhead interface temperature in the range from 12 K to 373 K and maintain an accuracy of ±0.05 K over the mission duration for the temperature range 12 K to 25 K, and ±1 K for the temperature range 25 K to 373 K.

3.2.2.3.2 Coldload Temperature Set Point Range. The 6K coldhead interface shall be capable of being set to any temperature ±0.1 K in the range from 6 K to 12 K (4 K to 12 K as a goal), and the 18K coldhead interface shall be capable of being set to any temperature ±0.1 K in the range from 18 K to 25 K (15 K to 25 K as a goal). The default temperatures of the 6K and 18K coldload interfaces shall be 6.0 K and 18.0 K, respectively.

3.2.2.4 ***Temperature Stability.*** The cryocooler shall provide the internal control provisions required to meet the coldload interface temperature stability requirements below.

3.2.2.4.1 6K Short-Term Temperature Stability. The cryocooler shall be capable of limiting the variation of the 6K coldload interface temperature to no greater than ±0.03 K over a 10-minute period with an attached thermal mass equivalent to 50 grams of copper and with the cooler thermal interfaces subject to the maximum rates of change defined in 3.2.4.3.2.

3.2.2.4.2 6K Long-Term Temperature Stability. The cryocooler shall be capable of limiting the variation of the 6K coldload interface temperature to no greater than ±0.1 K over a 24-hour period with an attached thermal mass equivalent to 50 grams of copper and with the cooler thermal interface temperatures subject to the maximum rates and 24-hour extremes defined in 3.2.4.3.2.

3.2.2.4.3 18K Short-Term Temperature Stability. The cryocooler shall be capable of limiting the variation of the 6K coldload interface temperature to no greater than ±0.1 K over a 10-minute period with an attached thermal mass equivalent to 250 grams of copper and with the cooler thermal interfaces subject to the maximum rates of change defined in 3.2.4.3.2.

3.2.2.4.4 18K Long-Term Temperature Stability. The cryocooler shall be capable of limiting the variation of the 18K coldload interface temperature to no greater than ±1.0 K over a 24-hour period with an attached thermal mass equivalent to 250 grams of copper and with the cooler thermal interface temperatures subject to the maximum rates and 24-hour extremes defined in 3.2.4.3.2.

3.2.2.5 *Lifetime*

3.2.2.5.1 Operating Life. The operating life of the cryocooler shall be no less than 60,000 hours; this includes the total of both in-space operation and ground-test operation.

3.2.2.5.2 Storage Life. The storage life of the cryocooler shall be no less than five years.

3.2.2.5.3 Start/Stop and Cooling Cycles. The cryocooler shall be capable of operating for no less than 500 start/stop cycles and 50 cryogenic cooling cycles over its operating life. A cryogenic cooling cycle consists of a cooldown from ambient to cryogenic temperatures and a warm-up from cryogenic to ambient temperatures.

3.2.2.5.4 Predicted End of life (EOL) Condition. The Predicted End-of-Life (EOL) Condition of the cryocooler is defined as the predicted physical status of the cooler after it has been exposed to ALL of the following environments:

1) Run at the Nominal Operating Point for the operating life defined by 3.2.2.5.1
2) Stored for the Storage Life defined by 3.2.2.5.2
3) Subjected to the Start/Stop and Cooling Cycles defined by 3.2.2.5.3
4) Subjected to three complete vibration test campaigns as defined in 4.4.5
5) Subjected to three complete thermal/vacuum test campaigns as defined in 4.4.2
6) Suffered the maximum leakage of working fluid as defined in 3.3.3.7
7) Subjected to the thermal-cycle environment defined in 3.3.3.8

3.2.3 Interfaces

3.2.3.1 *Structural Mounting Interfaces*

3.2.3.1.1 Compressor Assembly Mounting. The compressor assembly shall have structural mounting provisions that allow it to be efficiently supported from a host spacecraft and thermally coupled to an external heat rejection system per 3.2.3.3.1. The mounting provisions shall minimize redundant load paths that could result in static bending or warpage loads into the compressor leading to such things as loss of critical running clearances of moving components.

3.2.3.1.2 Coldhead Mounting. The coldhead(s) shall have mounting provisions that allow it (them) to be efficiently supported. Up to 2 kg of coldhead mass may be supported from the host instrument's 18K cold load and up to 250 grams may also be supported from the host instrument's 6K cold load. Any additional mass shall be supported from the instrument structure at 100 K.

3.2.3.1.3 Transfer Line Mounting. The gas transfer lines shall have mounting provisions that allow them to be efficiently supported between the compressor and coldhead. If desired, the gas transfer lines may be thermally coupled to the intermediate-temperature heat rejection system per 3.2.3.3.3.

3.2.3.1.4 Cooler Electronics Mounting. The cooler electronics shall be designed to be mechanically supported from the host spacecraft in a manner that is consistent with efficient structural support and removal of the heat dissipated by the electronics per 3.2.3.3.2. As a goal, the thermal interface shall be a flat rectangular conductive surface with an area less than 0.1 m^2 (1 ft^2), with provisions for being bolted to a flat mounting plate.

3.2.3.2 *Cryogenic Load Interface*

3.2.3.2.1 Cryogenic Load Mechanical Interface. The 6K and 18K coldheads shall be configured with bolted-joint conductive cryogenic load interfaces suitable for conducting the cryogenic loads to the cooler with a thermal resistance of < 0.5 K/W across the bolted joint and structurally supporting the coldheads from the cold loads.

3.2.3.2.2 Cryogenic Load Interface Flatness. The coldhead cryogenic interfaces shall be flat within ±0.001"/inch to assure a good thermal joint with the cold load interfaces.

3.2.3.3 *Heat Rejection Interfaces*

3.2.3.3.1 Compressor Heat Rejection Interface. The compressor assembly shall be configured with a conductive heat rejection interface suitable for extracting the power dissipated by the compressor. The heat rejection interface shall be designed to minimize the thermal drop between the compressor exterior and the S/C-supplied external heat rejection system, with a goal of maintaining it below 5°C under all operating conditions. The heat rejection system temperature shall be as defined in 3.2.4.3.1.

3.2.3.3.2 Cryocooler Electronics Heat Rejection Interface. The cryocooler electronics shall be configured with a conductive heat rejection interface suitable for extracting the dissipated power of the electronics. The heat rejection interface shall be designed to minimize the thermal drop between the electronics chassis and the S/C-supplied external heat rejection system, with a goal of achieving a drop of less than 5°C. The heat rejection system temperature shall be as defined in 3.2.4.3.1.

3.2.3.3.3 Intermediate Temperature Heat Rejection Interface. The cryocooler may assume the presence of an optional spacecraft-provided Intermediate Temperature Heat Rejection Stage that has the thermal load carrying capability shown in Fig. 3.2.3.3-1. If used, the cooler shall provide for attachment to this intermediate temperature heat rejection stage. The temperature of the Intermediate Temperature Heat Rejection Stage is defined on the Stage side of the thermal interface joint.

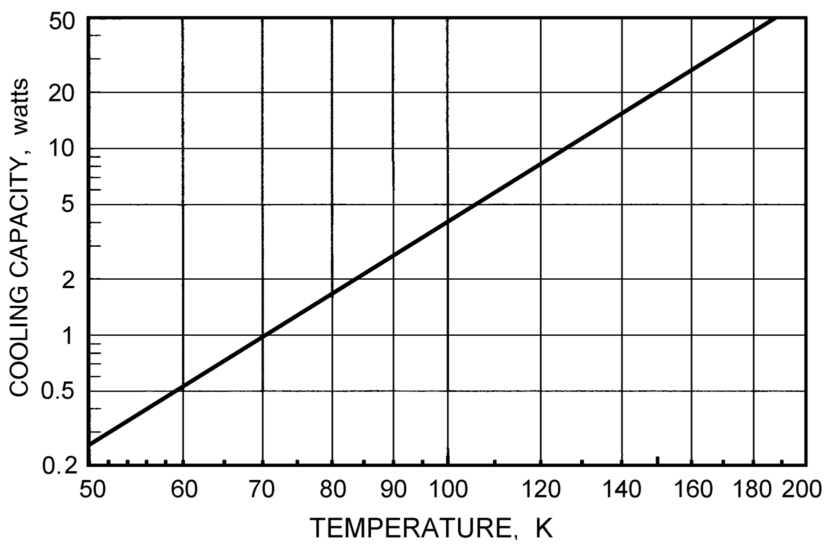

Figure 3.2.3.3-1. Available refrigeration capacity of spacecraft-provided Intermediate Temperature Stage at mission end-of-life (EOL) versus selected operating temperature.

3.2.3.4 *Electrical Interfaces*

3.2.3.4.1 Power Source Interface. The cryocooler shall operate in compliance with all performance specifications when supplied with primary power as specified below; the bus shall be a "dirty power bus" to isolate cryocooler-caused powerline noise from more sensitive instrument and spacecraft loads.

3.2.3.4.1.1 Input Voltage. The host S/C Power Subsystem will supply power at a nominal input voltage of +28 volts direct current (Vdc) with an allowable range of 22 Vdc to 34 Vdc. This is the full range of voltage at the cryocooler power input connector including the ripple voltage on the input power bus.

3.2.3.4.1.2 Power Source Impedance. The source impedance of the host power source, as viewed from the cryocooler power input connector, is as follows:

Frequency	Impedance
1 Hz to 1 kHz	0.1 ohm
1 kHz to 20 kHz	1.0 ohm
20 kHz to 100 kHz	2.0 ohms
100 kHz to 10 MHz	20 ohms

3.2.3.4.2 Command and Data Interface.

3.2.3.4.2.1 Command Input. Commands and data requests shall be issued to the cryocooler through a synchronous serial interface. The signal characteristics shall conform to the RS-422A standard.

3.2.3.4.2.2 Sync Clock Input. The cryocooler shall have a sync clock signal provided by the host. The signal characteristics of the clock input shall conform to the RS-422A standard. The cryocooler shall be capable of operating autonomously in the absence of this input.

3.2.3.4.2.3 Outputs. Each cryocooler shall have one output: a data output. Data is provided by the cryocooler through this synchronous serial interface in conjunction with the command clock input. The signal characteristics shall conform to the RS-422A standard.

3.2.4 Environmental Requirements

The cryocooler shall perform in accordance with the requirements of this specification after exposure to the handling and launch environmental conditions and during exposure to the ground operations and flight environmental conditions unless otherwise specified.

3.2.4.1 *Ground Operations and Handling Environment*

Ground operations and handling environmental requirements include those environments the cryocooler will encounter during assembly, integration, and testing until launch, as well as those environments the cryocooler will encounter during transportation and storage in shipping containers.

3.2.4.1.1 Ambient Air Temperature. The cryocooler shall perform in accordance with the requirements of this specification after exposure to an ambient air temperature range of 5°C to 45°C with a maximum transient temperature rate of change of 5°C per hour.

3.2.4.1.2 Ambient Pressure. The cryocooler shall perform in accordance with the requirements of this specification after exposure to an ambient pressure range of 795 torr to 10^{-8} torr.

3.2.4.1.3 Relative Humidity. The cryocooler shall perform in accordance with the requirements of this specification after exposure to a relative humidity range of 0 to 70% with no condensation permitted.

3.2.4.2 *Launch Environment*

The launch environmental requirements include those environments the cryocooler will encounter during on-pad and launch operations through spacecraft separation.

3.2.4.2.1 Launch Temperature Range. The cryocooler shall perform in accordance with the requirements of this specification after exposure to interface temperatures during launch equal to the Flight Allowable Non-operating temperature range specified in 3.2.4.3.1.

3.2.4.2.2 Atmospheric Pressure Decay During Launch. The cryocooler shall perform in accordance with the requirements of this specification after exposure to the atmospheric pressure decay from 1 bar to 0.05 bar as shown in Figure 3.2.4.2-1.

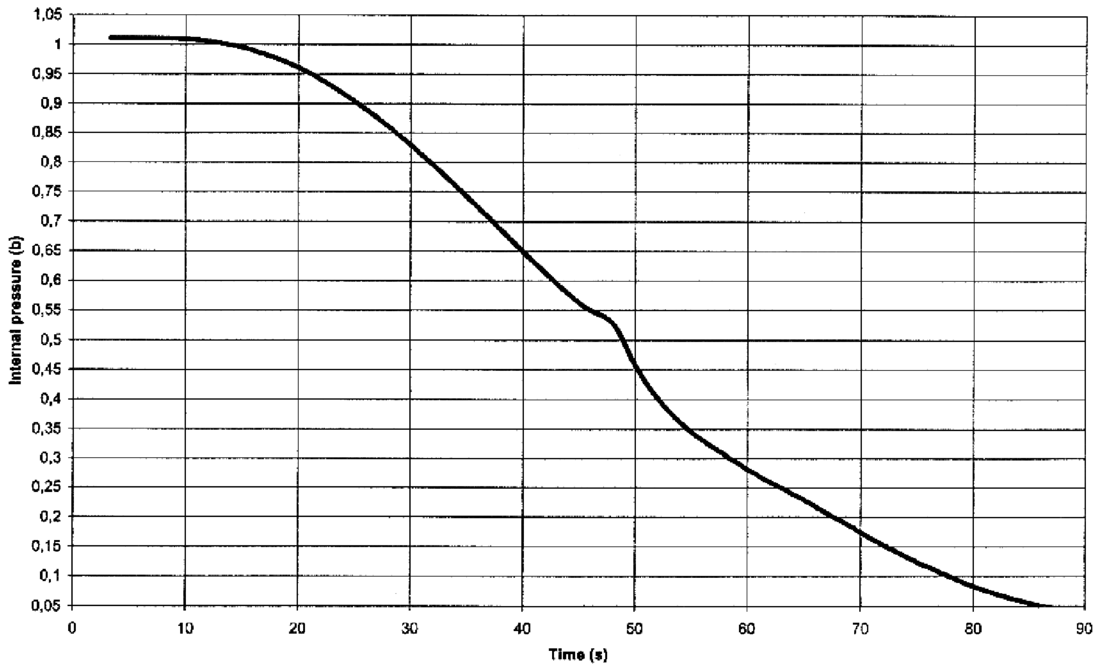

Figure 3.2.4.2-1. Pressure decay versus time during launch.

3.2.4.2.3 Random Vibration. The cryocooler shall perform in accordance with the requirements of this specification after exposure in each of three principal orthogonal axes to the Protoflight random vibration environment defined below; test duration shall be one minute per axis. Cryocooler mechanisms shall be caged per 3.3.3.6, and the cryocooler shall be mounted to a fixture that provides base-excited motion at the mounting interface specified in 3.2.3.1. The cryocooler shall be non-operational during the random vibration testing.

Frequency (Hz)	Compressor	Coldhead	Cooler Elect.
20 to 80	+6 dB/oct	+6 dB/oct	+6 dB/oct
80 to 500	0.2 g^2/Hz	0.5 g^2/Hz	0.2 g^2/Hz
300 to 2000	-6 dB/oct	-6 dB/oct	-6 dB/oct

3.2.4.2.4 Sinusoidal Vibration. The cryocooler shall perform in accordance with the requirements of this specification after exposure in each of three principal orthogonal axes to the sinusoidal vibration environment defined below. There shall be one upsweep for each axis at a sweep rate of 2 oct/min. For frequencies where peak-to-peak stroke exceeds the shaker maximum stroke capability, the acceleration shall be limited to a fixed double amplitude. Cryocooler mechanisms shall be caged per 3.3.3.6, and the cryocooler shall be mounted to a fixture that provides base-excited motion at the mounting interface specified in 3.2.3.1. The cryocooler shall be non-operational during vibration testing. The sinusoidal vibration testing is not required if the minimum resonant frequency of the component under test is greater than 150 Hz.

Frequency (Hz)	Level
5 to 100	15 g peak

3.2.4.2.5 Resonant Frequency Stability. Following exposure to the random and sine vibration environments of 3.2.4.2.3 and 3.2.4.2.4, the principal cryocooler resonant frequencies shall not have changed by more than 5%. This determination shall be made by conducting a resonance search before and after Random and Sinusoidal testing in each axis using a sinusoidal frequency sweep between 5 to 2000 Hz with a peak level of 0.25 g (sweep rate: 2 Oct./min.). Any frequency shift between the before and after sweeps of more that 5% shall be investigated as a possible structural failure.

3.2.4.3 ***Flight Structural/Thermal Environments***. The flight Structural/Thermal environmental requirements include those mechanical environments the cryocooler will encounter during on-orbit operation over its lifetime.

3.2.4.3.1 Thermal Interface Temperatures. The cryocooler shall be designed to operate successfully over a broad range of S/C interface temperatures as defined in Table 3.2.4.3-1. All performance specifications are to be met for the range of temperatures defined as "Flight Allowable-Operating." Non-operating Flight Allowable temperatures are the mission temperature extremes (including allowance for prediction uncertainties) that the hardware will experience in a worst-case, powered-off, non-operational mode. The range of temperatures defined as "Protoflight-Operating" are the flight temperatures with margin for which the cryocooler shall demonstrate that it is fully operational, though refrigeration capacity may be degraded by up to 10%. "Protoflight-Non Operating" temperatures are non-operating temperature extremes, with margin, for which the cryocooler shall demonstrate that it can survive.

Table 3.2.4.3-1. Thermal Interface Temperatures.

Assembly		Flight Allowable		Protoflight	
	Baseline	Operating	Non-Operating	Operating	Non-Operating
Compressor Heatsink*	T_{CH}°C	(T_{CH}-20) to (T_{CH}+20)	(T_{CH}-35) to +50°C	(T_{CH}-35) to (T_{CH}+35)	(T_{CH}-55) to +70°C
Intermediate Heatsink	TBD	TBD	30 K to 50°C	TBD	20 K to 70°C
Electronics Heatsink	+20°C	0°C to +40°C	-15°C to +55°C	-20°C to +60°C	-35°C to +75°C

* Baseline Compressor Heatsink temperature (T_{CH}) may be selected by cooler manufacturer in the range: $-50°C \le T_{CH} \le 15°C$; the preferred value (goal) for S/C thermal accommodation is $T_{CH} = 15°C$.

3.2.4.3.2 Thermal Interface Temperature Stability. The cryocooler shall be designed to meet its refrigeration performance requirements of 3.2.2 while connected to thermal interfaces that fluctuate as noted below during periods of cryocooler operation:

Assembly	Max. Rate of Change	Extremes per Day	Extremes per Mission
Compressor Heatsink	0.2°C/min	±3°C	(T_{CH}-20) to (T_{CH}+20)
Intermediate Heatsinks	TBD	±1 K (TBC)	TBD
Electronics Heatsink	0.2°C/min	±3°C	0°C to +40°C

3.2.4.3.3 Space Vacuum. The cryocooler shall perform in accordance with the requirements of this specification during exposure to vacuum levels from 760 torr to 2×10^{-10} torr.

3.2.4.3.4 Acceleration. The cryocooler shall perform in accordance with the requirements during exposure to an acceleration of up to 0.02 g during space operation.

3.2.4.4 *Space Radiation Environments*

3.2.4.4.1 Total Ionizing Dose. The five-year total ionizing dose radiation environment is defined in Fig. 3.2.4.4-1 for spherical aluminum shields. The cryocooler shall perform in accordance with the requirements of this specification during exposure to two times the total dose to yield an ionization radiation dose margin (RDM) of two. The effect of shielding materials other than aluminum shall be treated to first approximation by using the ratio of the material densities to determine the equivalent thickness of aluminum. Similarly, total ionizing dose in materials other than silicon may be determined by using appropriate conversion factors.

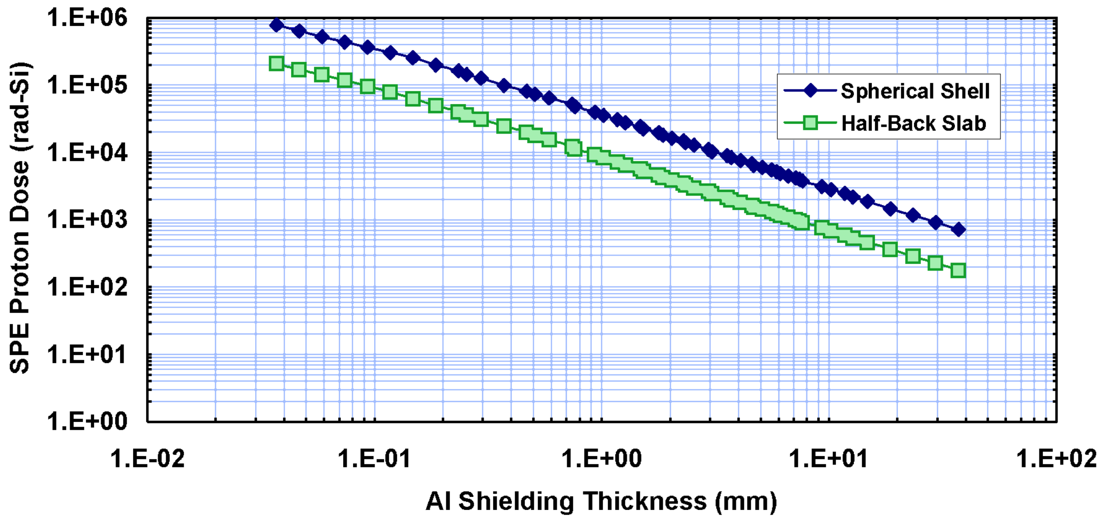

Figure 3.2.4.4-1. Total 5-year ionizing dose versus shielding thickness.

3.2.4.4.2 Internal Charging. Metallic elements, including wires, unused conductors of cable, connectors, circuit board traces, and spot shields, shall have a conductive path to ground of less than 10^8 ohms when measured in air and less than 10^{12} ohms when measured in vacuum. Since the internal charging environment is only moderate, components that are shielded from the external radiation environment by greater than 0.3 cm of aluminum (or equivalent) are not susceptible to internal charging and need not be grounded.

3.2.4.5 *Electromagnetic, Electrostatic, and Magnetic Requirements*

3.2.4.5.1 Conducted Emissions, Power Leads

3.2.4.5.1.1 Current Change Rate. The rate of change of the cryocooler's current on the input power bus shall be no greater than 500 mA/microsecond over a 100-microsecond average.

3.2.4.5.1.2 Turn-On Transient Current. The turn-on transient current drawn from the primary power bus during the cryocooler's turn-on shall be no greater than 10 A. The transient duration shall be no greater than 50 msec.

3.2.4.5.1.3 Turn-Off Transient Voltage. Upon sudden removal of primary power from the cryocooler, the voltage transient generated on the cryocooler side of the open-circuited power bus shall remain within the range -2 Vdc to +40 Vdc.

3.2.4.5.1.4 Total Reflected Ripple Current. The total peak-to-peak load current ripple generated by the cryocooler shall be no greater than 25% of the average current.

3.2.4.5.1.5 Narrowband Emissions (CE01/CE03). The cryocooler's narrowband conducted emissions on power and power return leads shall be limited to the levels defined in Fig. 3.2.4.5-1 when measured in accordance with the CE01 (30 Hz to 20 kHz) and CE03 (20 kHz to 50 MHz) test methods of MIL-STD-462. The measurement bandwidth shall be as defined in Figure 3.2.4.5-1.

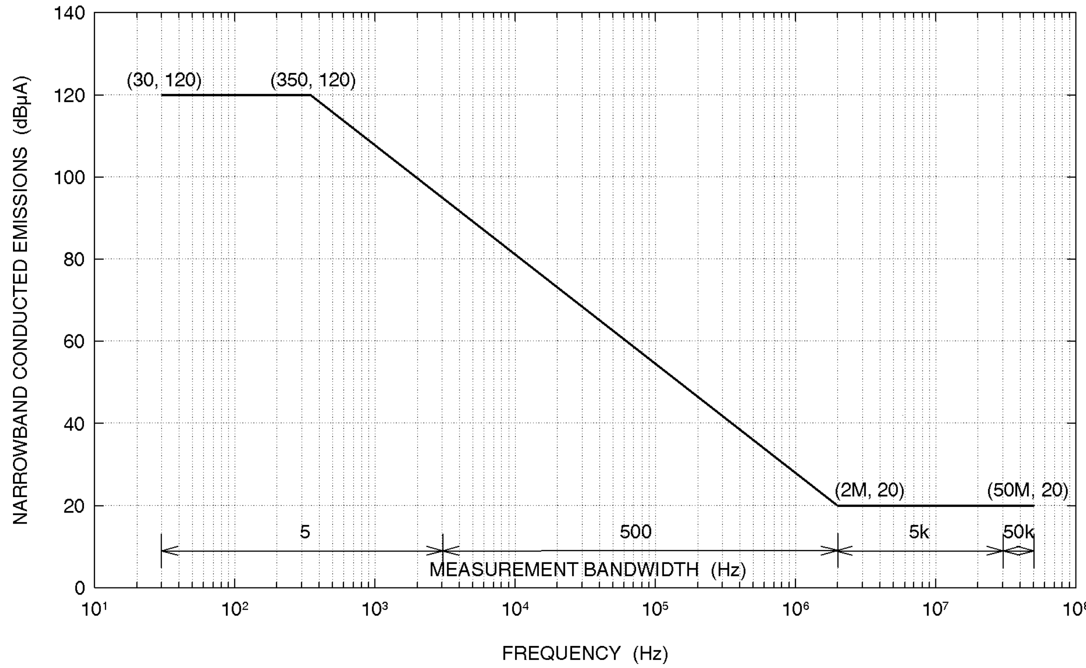

Figure 3.2.4.5-1. Allowable levels of narrowband conducted emissions.

3.2.4.5.1.6 Broadband Emissions (CE03). The cryocooler's broadband conducted emissions on power and power return leads shall be limited to the levels defined in Fig. 3.2.4.5-2. over the frequency range of 20 kHz to 50 MHz when measured in accordance with the CE03 test method of MIL-STD-462. The measurement bandwidth shall be as defined in Figure 3.2.4.5-2. Larger measurement bandwidths may be used; however, no bandwidth correction factors shall be applied to test data due to use of larger bandwidths.

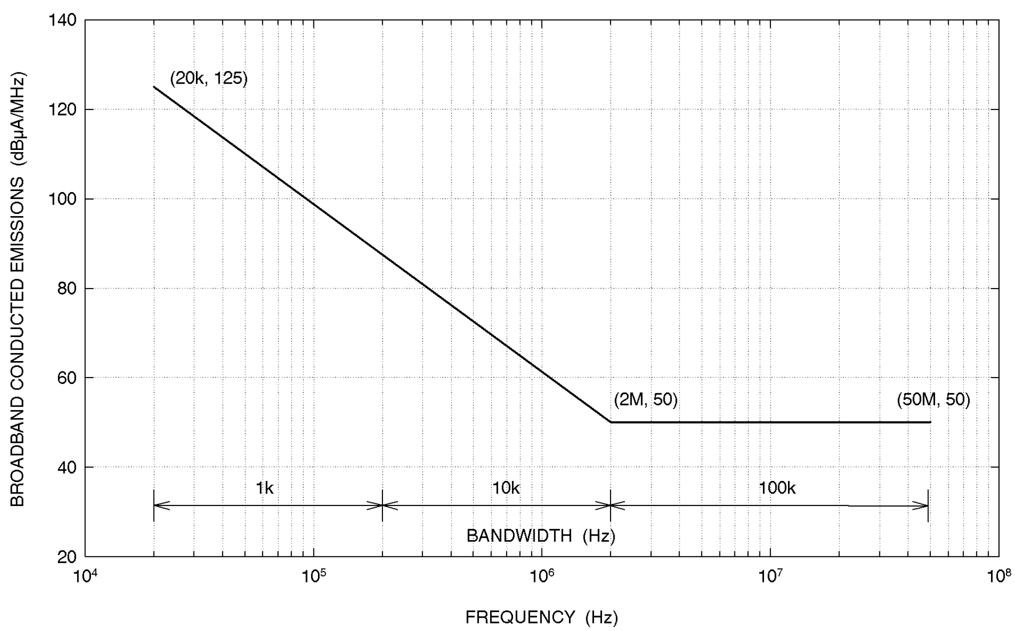

Figure 3.2.4.5-2. Allowable levels of broadband conducted emissions.

3.2.4.5.2 Conducted Susceptibility, Power Leads (CS01/CS02). The cryocooler shall perform in accordance with the requirements of this specification during exposure to a sine wave superimposed on the bus voltage of each input power lead using the CS01 (30 Hz to 20 kHz) and CS02 (20 kHz to 400 MHz) test methods of MIL-STD-462. The amplitude of the superimposed sine wave is defined in Figure 3.2.4.5-3. The tests shall be performed for a bus voltage of 28 Vdc.

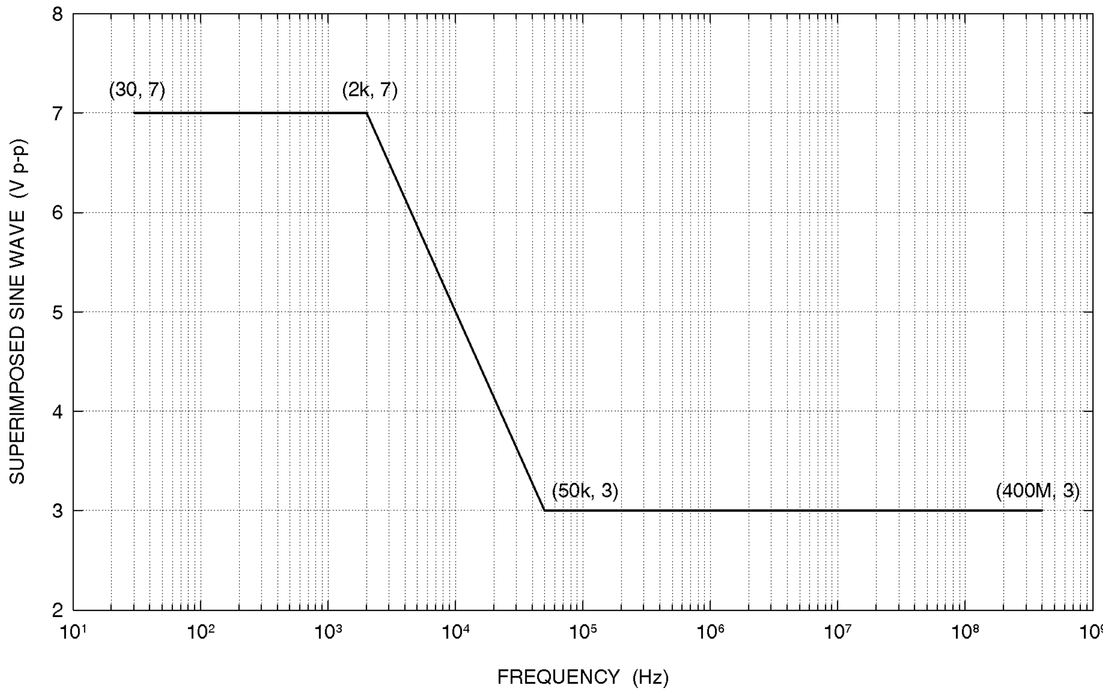

Figure 3.2.4.5-3. Definition of superimposed sine voltage for conducted susceptibility testing.

3.2.4.5.3 Conducted Susceptibility, Spike, Power Leads (CS06). The cryocooler shall perform in accordance with the requirements of this specification during exposure to positive and negative spikes applied to each input power lead using the CS06 test method of MIL-STD-462. The spikes shall have a peak voltage equal to the steady-state power bus voltage and a pulse width (t_0) of 10 microseconds. The waveform of the spike is defined in Figure 3.2.4.5-4. The spikes shall be applied at a repetition rate of 60 pulses per second for a duration of five minutes.

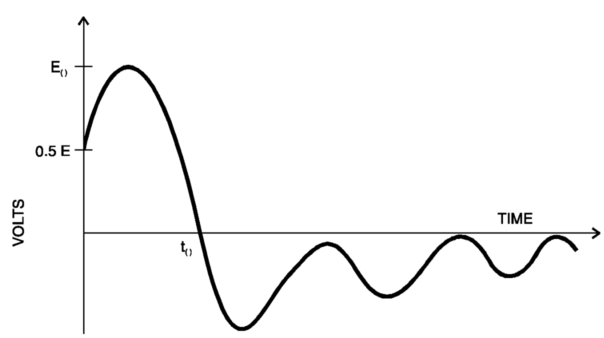

Figure 3.2.4.5-4. Representative positive transient waveform.

3.2.4.5.4 Radiated Emissions, Magnetic Field

3.2.4.5.4.1 Radiated AC Magnetic Field Emissions (RE01/RE04). The cryocooler's radiated ac magnetic field emissions shall be limited to the levels defined in Fig. 3.2.4.5-5 when measured in accordance with the RE01 (7 cm) and RE04 (1 m) test methods of MIL-STD-462. The measurement bandwidth shall be as defined in Fig. 3.2.4.5-5.

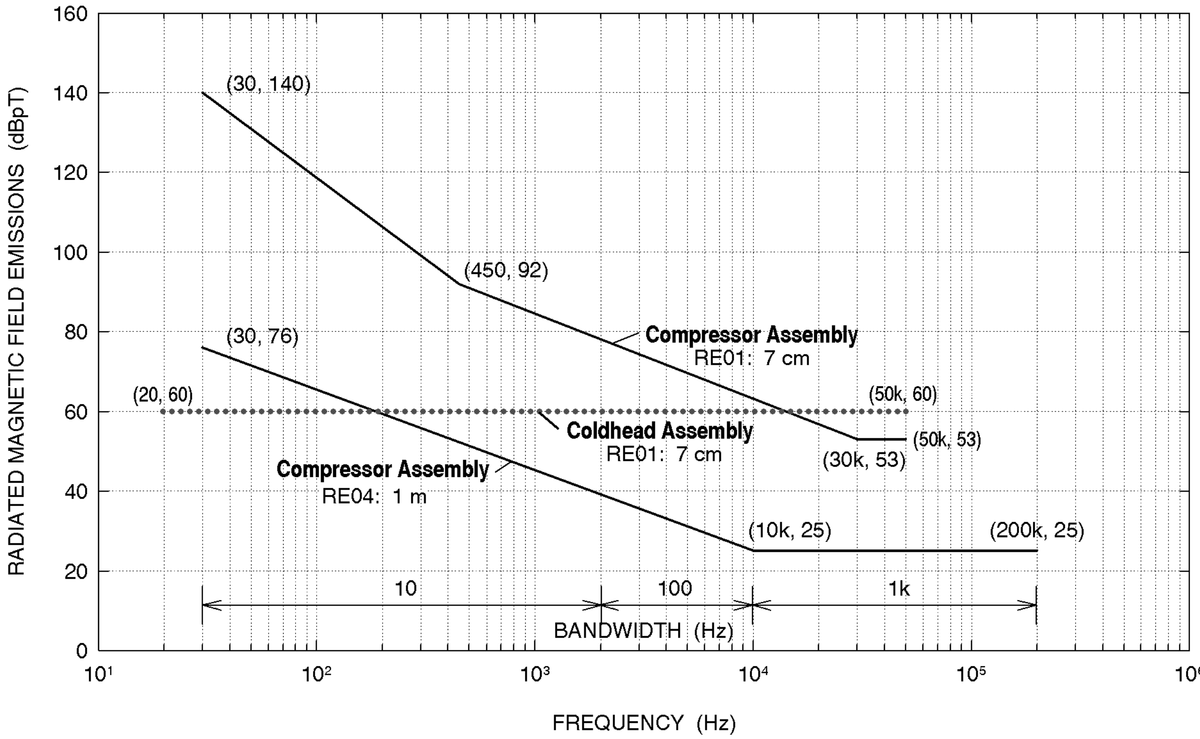

Figure 3.2.4.5-5. Radiated AC magnetic field emissions (RE01/RE04) requirements.

3.2.4.5.4.2 Radiated DC Magnetic Field Emissions. The maximum dc dipole moment produced by the mechanical cooler shall not exceed 0.5 A·m^2 (dipole moment).

3.2.4.5.5 Radiated Emissions, Electric Field (RE02)

3.2.4.5.5.1 Narrowband Emissions. The cryocooler's narrowband radiated electric field emissions shall be limited to the levels defined in Fig. 3.2.4.5-6 when measured in accordance with the RE02 test method of MIL-STD-462 over the frequency range of 14 kHz to 18 GHz. The measurement bandwidth shall be as defined in Fig. 3.2.4.5-6.

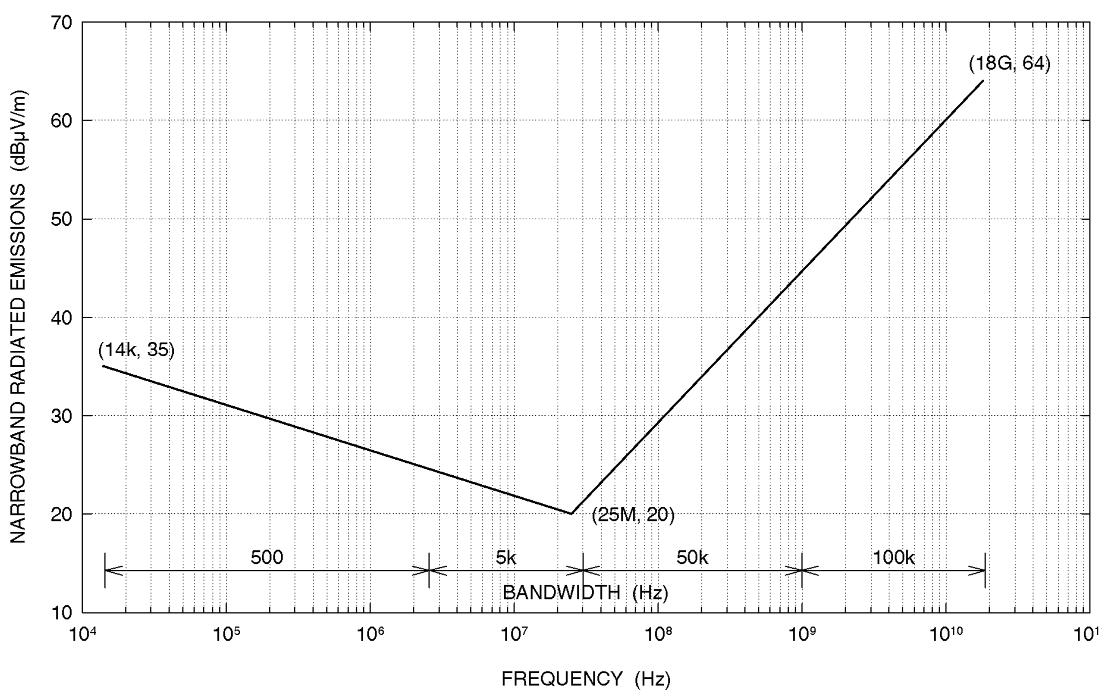

Figure 3.2.4.5-6. Allowable levels of radiated narrowband electric field (RE02) emissions.

3.2.4.3.5.2 Broadband Emissions. The cryocooler's broadband radiated electric field emissions shall be limited to the levels defined in Figure 3.2.4.5-7 when measured in accordance with the RE02 test method of MIL-STD-462 over the frequency range of 14 kHz to 18 GHz. The measurement bandwidth shall be as defined in Figure 3.2.4.5-7.

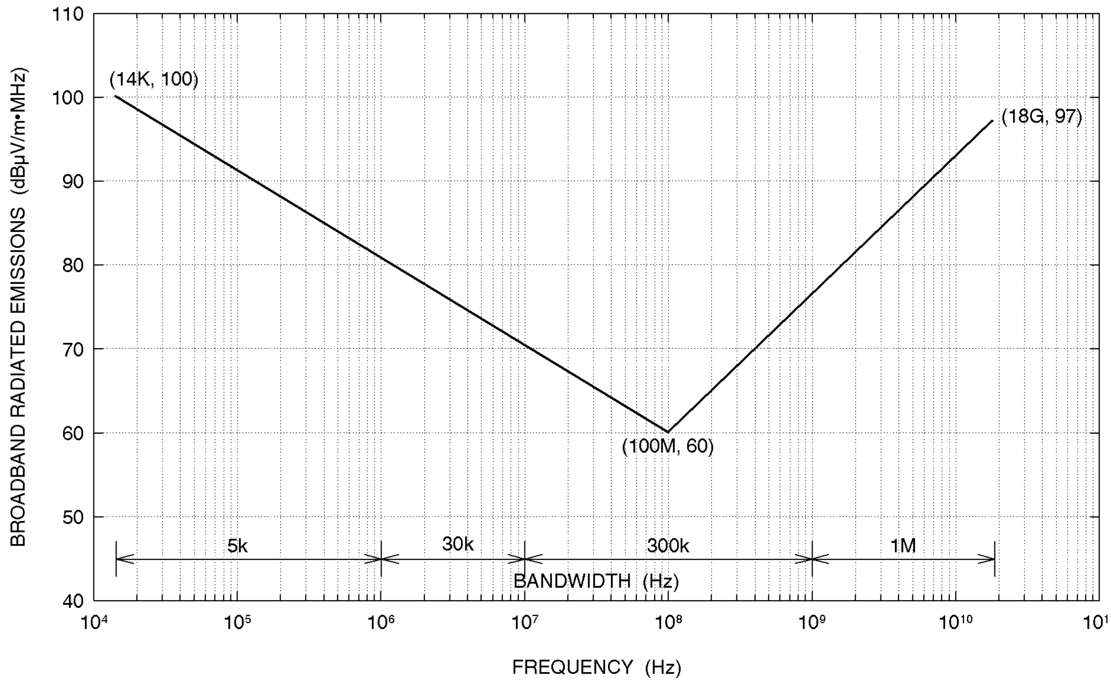

Figure 3.2.4.5-7. Allowable levels of radiated broadband electric field (RE02) emissions.

3.2.4.5.6 Radiated AC Magnetic Field Susceptibility (RS01). The cryocooler shall perform in accordance with the requirements of this specification during exposure to the ac magnetic field defined in Fig. 3.2.4.5-8 using the RS01 test method of MIL-STD-462.

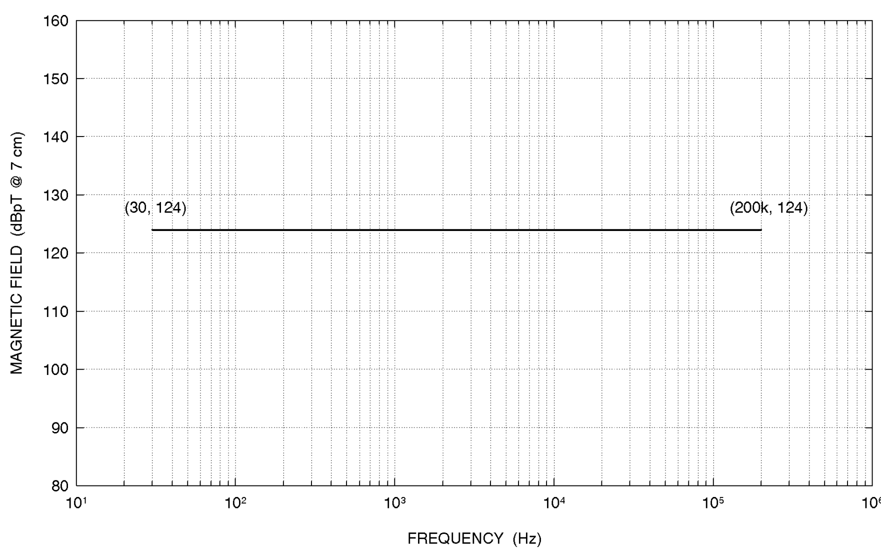

Figure 3.2.4.5-8. Cryocooler magnetic susceptibility environment.

3.2.4.5.7 Radiated Susceptibility, Electric Field (RS03). The cryocooler shall perform in accordance with the requirements of this specification during exposure to the radiated electric field defined below using the RS03 test method of MIL-STD-462.

Frequency	Electric Field Strength
14 kHz to 2 GHz	2 V/m
2 GHz to 18 GHz	10 V/m
except:	
2.2875 GHz ± 2 MHz	20 V/m
8.16 GHz ± 100 MHz	20 V/m

3.2.5 Operational

3.2.5.1 ***Startup/Shutdown Conditions***. Devices utilizing microprocessors, micro-controllers, FPGAs, memory devices, and digital circuitry shall implement an orderly internal sequence for startup and shutdown into known logic states. Neither power turn-on nor interruption shall produce commands that could cause failure, deleterious action, or re-configuration in any devices, components, or subsystems. The startup sequence may include boot-up, self-test, and initialization where appropriate.

3.2.5.2 ***Abnormal Conditions***. The cryocooler shall not incur damage or permanent degradation from any abnormal condition described below. The cryocooler shall meet all performance requirements after a normal power-on reset and turn-on sequence following the removal of the abnormal condition.

3.2.5.2.1 Abnormal Input Voltage. The cryocooler shall survive steady-state voltages in the range 0 Vdc to 36 Vdc and momentary (no greater than 10 msec) voltages in the range 0 Vdc to 42 Vdc.

3.2.5.2.2 Unannounced Power Loss. The cryocooler shall survive the unannounced removal and arbitrary reconnection of primary power. The unit shall be capable of withstanding without damage a slow voltage rise on turn-on or drop-off when the voltage falls below 20 Vdc.

3.2.5.2.3 Unannounced Clock Signal Loss. The cryocooler shall survive the unannounced removal and arbitrary reconnection of the external synchronization clock signal.

3.2.5.2.4 Unannounced Digital Command Interface Loss. The cryocooler shall survive the unannounced removal and arbitrary reconnection of the digital command interface.

3.2.5.3 ***Autonomous Operation***. Following entering Normal Mode operation per 3.1.1.4, the cryocooler shall be designed to perform nominal cooling without operator intervention for a period of up to 1 year.

3.2.5.4 ***Survival Configuration***. When autonomous cooler-initiated recovery actions are exhausted, or an allowed recovery period has timed out, the cryocooler shall enter into a safe configuration from which it may recover with operator intervention.

3.2.5.5 ***Operating Orientation.*** The cryocooler must be fully operational in any orientation for the purposes of ground testing. Any effect of orientation on performance shall be quantified.

3.2.5.6 ***Short Functional Test.*** To be consistent with S/C and instrument-level testing the cryocooler shall be capable of demonstrating the health of its principal functions and interfaces in tests at ambient temperature and pressure and lasting less than 30 minutes.

3.2.5.7 ***Electrical Ground Test Requirements***
There are two hardware items designed to be used to operate the ACTDP cryocooler in the ground test environment: the Brassboard Electronics (BE) unit, which is self contained, and the EM Electronic's rack-mounted Electrical Ground Support Equipment

(EGSE); the EGSE is required to interface with, power, and operate the EM electronics in the lab environment when no spacecraft interface is present.

3.2.5.7.1 Input Power. The BE and EGSE shall operate from 110-volt, 60-Hz power.

3.2.5.7.2 Ground Test Components. The BE and EGSE shall include as a minimum the following components to monitor and operate the cryocooler during ground testing.

a. Hardware and software to simulate the nominal power input to the cooler.
b. Hardware and software to simulate all external command and data monitoring of the cryocooler performance that would be expected during ground and orbital operation.
c. Temperature sensors, heaters, and temperature controllers to monitor and control the 6K and 18K coldload interface temperatures.
d. True-rms power meters to monitor the power supplied to the mechanical cryocooler (BE and EGSE), and EM electronics (EGSE only).
e. Voltage and current monitoring devices to determine the power supplied to the coldload interface heaters.

3.2.5.7.3 Ground Test Interlocks. The BE and EGSE shall incorporate provisions to protect the cryocooler from damage. These shall include as a minimum the following:

a. A manual shutdown button in addition to the nominal shutdown sequence.
b. Automatic shutdown of the coldload interface heaters in the event of excessive coldload interface temperatures.
c. Automatic shutdown of the mechanical cooler in the event of excessive compressor temperature.
d. Automatic shutdown of the mechanical cooler in the event of excessive drive level.

3.3 DESIGN AND CONSTRUCTION

The individual design and construction line items below are representative of those for a flight-model cryocooler and are intended to guide the ACTDP cryocooler design effort. In many cases, the EM and Brassboard hardware deliverables need only meet a subset of these requirements as defined in the Product Verification Matrix presented in Table 4.3-1. As an example, the ACTDP cryocooler electronics design should be based on the availability of flight electronic parts and packaging concepts meeting the requirements below. However, in general, the EM electronics delivery option hardware, which shall contain flight-like circuits, packaging and system interfaces, shall be fabricated using equivalent commercial-grade parts and processes. Similarly, the Brassboard electronics, which shall be capable of carrying out flight operational functions, need NOT have flight-like circuits, packaging, or power-system interfaces.

3.3.1 Parts, Materials and Processes

Cryocooler flight equipment parts, materials, and processes shall be selected from among those which have proved successful in similar applications in space flight missions, or the part, material, or process shall have completed a rigorous program to qualify it for it's application and mission.

3.3.1.1 ***Materials.*** The cryocooler shall use only materials rated “A” in MSFC-HDBK-527 for flammability, thermal vacuum stability, stress corrosion cracking, corrosion, and, if applicable, high pressure hydrogen compatibility. The following materials shall not be used: mercury, polyvinyl chloride, carcinogenic or toxic materials, radioactive sources, shatterable or flaking materials, beryllium or its alloys, cadmium, and zinc.

3.3.1.2 ***Electronic Parts.*** Only parts of acceptable quality, reliability, total ionizing dose (TID) and single event effect (SEE) tolerance per 3.3.1.2.1 through 3.3.1.2.5, as demonstrated through qualification and/or verified performance, shall be selected for application in the **flight cryocooler**. Parts shall be selected in the following sequence: 1) JPL Approved Parts List, 2) Standard parts as listed in MIL-STD-975, 3) Non standard parts. The first order of preference for standard EEE parts, in the absence of inclusion on an approved parts list, is MIL-STD-975 Grade 1, or Grade 2 with the required upgrading testing for parts used in critical applications. Before the fabrication of **flight hardware** the use of each nonstandard part will have to be approved through the submittal of a 'nonstandard parts request', (NSPAR). *For the ACTDP cryocooler, circuit designs should be based on the availability of parts meeting flight requirements. Lower grade parts of acceptable electrical performance may then be used in fabricated and delivered EM hardware. Brassboard hardware need not use flight circuits, or flight-like components and fabrication processes.*

3.3.1.2.1 Radiation Tolerance. Flight electronic parts shall be selected for a minimum radiation dose margin (RDM) of 2X over the expected total dose ionizing radiation environment shown in Figure 3.2.4.4-1. An aluminum shielding thickness of 2.5 mm (100 mils) may be assumed when using an electronic box with 1.25 mm (50 mil) thick walls.

3.3.1.2.2 Single Event Effects (SEE). Flight semiconductor parts shall be selected to be resistance to single event upset, latch-up, burnout and gate rupture (collectively referred to as SEE) caused by high energy ionized particle radiation. The linear energy transfer (LET) threshold of parts sensitive to SEE shall be greater than 75 MeV/mg/cm^2 or shall have a tolerable device upset rate per 3.3.1.2.3. SEE sensitive parts that have no SEE data available or that do not meet the LET threshold level shall not be used in hardware without an approved waiver.

3.3.1.2.3 Single Event Upset (SEU). For single event upsets (i.e.,"soft" errors), all flight digital microcircuits containing storage elements (e.g., flip flops, counters, RAMs, microprocessors, etc.) shall be characterized to allow cryocooler-level SEU rates to be assessed. The cryocooler-level SEU rate shall not exceed 2 major upsets/year. A major upset is defined as an interruption in normal cooler operation that requires corrective action.

3.3.1.2.4 Single Event Latch-up (SEL). All flight bulk CMOS devices (including those with epitaxial layers) shall be subject to latch-up evaluation. Bipolar, SOS, SOI and DI (dielectrically isolated) devices need not be evaluated. Parts that exhibit latch-up are not acceptable. The establishment of no latch-up shall be determined at an effective LET = 75 MeV/mg/cm^2 and a fluence of 10^7 ions/cm^2.

3.3.1.2.5 Single Event Burnout and Gate Rupture. Flight components, including power transistors and power MOSFET's, that are susceptible to single event gate rupture or burnout shall not be utilized in the cryocooler design.

3.3.1.2.6 Operating-Limit Derating. Part operating-limit parameters such as maximum voltage, maximum current, and maximum operating temperature shall follow the parts derating guidelines established in JPL document D-8545, Rev B.

3.3.1.3 ***Electronic Packaging***

Flight electronics shall be packaged using qualified space-rated electronic packaging techniques designed for vacuum operation and conductive heat transfer to the external heat-rejection surface. Preferred packaging concepts are defined in JPL D-8208.

3.3.1.3.1 Thermal Cycle Endurance. Flight printed wiring board assemblies with all process elements including component mounting (with any heat sinking), soldering method, and conformal coating shall be capable of surviving 100 thermal cycles from +100°C to -35°C without experiencing failures such as cracked PWB elements or cracked solder joints. Prior to acceptance for flight, demonstration of this capability shall be carried out on flight-like hardware constructed using flight-like parts and flight processes, but shall not be performed on hardware to be flown.

3.3.1.3.2 Minimum Circuit Board Resonant Frequency. When installed in their mounting structure, all populated printed wiring boards shall be have a resonant frequency greater than 250 Hz, and as a goal, shall have a resonant frequency greater than 350 Hz.

3.3.1.3.3 Maximum Part Junction Temperatures. The maximum junction temperature of any electronic part shall be less than 110°C during Protoflight-Operating heatsink conditions as described in 3.2.4.3.1.

3.3.1.4 ***Connectors***

3.3.1.4.1 Keying. Connectors shall be of different sizes, different types, or uniquely keyed to prevent improper connection during cryocooler integration.

3.3.1.4.2 Connector Types. All connectors to be used by the cryocooler shall be selected from JPL-STD00009 or JPL-approved contractor equivalent.

3.3.2 Isolation, Grounding, and Shielding

3.3.2.1 ***Chassis Ground***. The cryocooler shall not use chassis ground to conduct power currents. Only fault, and leakage currents shall be conducted through chassis grounds.

3.3.2.2 ***Primary Power Isolation***. The cryocooler primary power (28 Vdc) leads and returns shall be isolated from signal and chassis ground by no less than 1 megohm (dc).

3.3.2.3 ***Secondary Power Isolation***. The cryocooler secondary power shall be isolated from primary power by no less than 1 megohm (dc) and shall use a single point ground to the electronic chassis.

3.3.2.4 ***Motor Drive Isolation***. All cryocooler motors shall be driven by secondary power and shall be isolated from primary power.

3.3.2.5 ***Signal Conductor Shielding***. All signal interfaces shall use shielded conductors. Conductors may include, but are not limited to, twisted pair, coaxial, twinaxial, and dual coaxial types.

3.3.3 Mechanical Design Requirements

3.3.3.1 ***Minimum Resonant Frequency***. The minimum fixed-base resonant frequency of the cryocooler including mounting brackets shall be no less than 150 Hz. Limited-mass components such as flexure-supported piston/displacer assemblies and small gage transfer line tubing may have resonant frequencies below 150 Hz, but must have provisions such as launch latches, as described in 3.3.3.6, to insure that they are not damaged by low-frequency sinusoidal excitation.

3.3.3.2 ***Compressor Assembly Self-Induced Vibration***. The vibratory force imparted by the cryocooler compressor assembly into its supports when rigidly mounted shall be no greater than 0.25 newtons zero-to-peak for any individual drive-frequency harmonic in any axis.

3.3.3.3 ***Coldhead Assembly Self-Induced Vibration***. The vibratory force imparted by the cryocooler coldhead into its coldload support when rigidly mounted shall be no greater than 0.025 newtons zero-to-peak for any individual drive-frequency harmonic < 200Hz and no greater than 0.25 newtons zero-to-peak at any harmonic ≥200Hz in any axis.

3.3.3.4 ***Coldhead Differential Motion Capability***. The cryocooler shall be capable of operating and meeting the operational lifetime requirement of 3.2.2.5.1 following the application of 10,000 cycles of relative motion of ±5 mm (±0.2") amplitude between the 6K and 18K coldload attachment interfaces, and 10,000 cycles of ±10 mm (±0.4") amplitude between the 18K coldload attachment interface and the compressor assembly attachment interface.

3.3.3.5 ***Coldhead Applied Force Capability***. The cryocooler shall be capable of operating and meeting the operational lifetime requirement of 3.2.2.5.1 with a continuous force of 5.0 newtons applied to either the 6K or 18K coldhead interfaces in any direction.

3.3.3.6 ***Caging of Cryocooler Mechanisms***. Cryocooler mechanisms that require restraint during launch shall be caged or damped during launch without requiring power to maintain the constrained condition. The cryocooler shall include provisions for caging or damping these mechanisms via the command input. It shall be possible to cage and uncage these mechanisms at least 500 times. There shall be a positive indication of the cage status available to the cryocooler remote operator.

3.3.3.6.1 Ground Support Caging Devices. The cryocooler shall be supplied with ground support caging devices such as motor shorting plugs if the launch caging approach is to be separated from the mechanism in need of caging during cryocooler transportation, handling, or vibration testing.

3.3.3.7 ***Leak Rate***. The leak rate of the refrigerant working fluid from the cryocooler compressor shall result in no greater than a one-percent gas loss over the storage life and operating life specified in 3.2.2.5. No measurable leakage from the coldhead or transfer lines is allowed, as measured by a helium mass spectrometer calibrated to at least 10^{-9} sccs sensitivity.

3.3.3.8 ***Mechanical Cooler Thermal-Cycle Endurance***. The mechanical cryocooler compressor, coldhead and piping assemblies shall be capable of surviving 200 thermal cycles from +35°C to the lower Flight Allowable Operating temperature per Table 3.2.4.3-1 without experiencing failures such as leaks or loss of critical allignments. For the coldhead assembly, the lower temperature-cycle temperature shall be 18 K. Demonstration of thermal-cycle endurance shall be carried out on flight-like hardware constructed using flight-like parts and assembly processes, but shall not be performed on flight hardware.

3.3.4 Thermal Design Requirements

3.3.4.1 ***Coldhead Off-State Thermal Conductance***. The off-state thermal conductance of the cryocooler coldheads shall be less than 1.0 mW into the 6K coldload interface, and 25 mW into the 18K coldload interface with all other heat rejection interfaces at their Baseline temperatures per 3.2.4.3.1.

3.3.5 Electrical Design Requirements

3.3.5.1 ***Power Filtering***. The cryocooler shall not use inductors with hard gaps for power filtering. All such inductors shall have a distributed gap, e.g. a powder core.

3.3.5.2 ***Suppression Devices***. The cryocooler shall use suppression devices such as diodes across all relay coils or other energy sources that could induce transients on the power lines during turn-off. Devices shall be located at the source of the inductive transients.

3.3.5.3 ***Electrical Synchronization***. The cooler electronics shall be synchronized with the command clock whenever the command clock is present. The cryocooler shall be capable of autonomous operation in the absence of the clock.

3.3.6 Command and Data Handling Requirements

3.3.6.1 ***Command Response***. The cryocooler shall respond to valid commands received over the command interface.

3.3.6.1.1 Command List. The list of valid commands is expected to include as applicable: enter standby mode, enter normal mode, enter shutdown mode, enable temperature control, disable temperature control, set coldload interface temperature, set compressor drive level, set expander drive level, set balancer drive level, compressor(s) on, compressor(s) off, expander(s) on, expander(s) off, balancer(s) on, balancer(s) off, set compressor-to-expander phase, enable vibration control, disable vibration control, cage compressor(s)/expander(s), uncage compressor(s)/expander(s), data request, memory load, and other commands to be defined by the contractor and JPL.

3.3.6.2 ***Command Constraints***

3.3.6.2.1 Toggle Commands. No state-dependent or “toggle” commands shall be used.

3.3.6.2.2 Critical Commands. Initiation of critical or hazardous functions shall use, as a minimum, separate enable and execute commands to prevent inadvertent execution of critical commands.

3.3.6.2.3 Override of Automatically Triggered Functions. Commands shall be available to override all functions automatically triggered by software.

3.3.6.2.4 Command Execution Verification. Command execution shall be verifiable via telemetry.

3.4.5.3 ***Data Message Response***. In response to a valid data-request command received over the command interface, the cryocooler shall respond with a data message.

3.4.5.3.1 Data Message List. The list of valid data messages is expected to include as applicable: temperature control enabled/disabled, coldload interface temperature set point, coldload interface temperature monitor (coarse or fine), compressor(s) drive level, expander(s) drive level, balancer(s) stroke, compressor(s) on/off status, expander(s) on/off status, balancer(s) on/off status, compressor-expander phase angle, vibration control enabled/disabled, compressor and coldhead vibration monitors (one axis), cage compressor(s)/expander(s) status, compressor housing temperature, coldhead housing temperature, power supply temperature, secondary voltage monitors, compressor drive current, expander drive current, checksums on memory data, memory data readout of a specified address range, software version, and other data messages to be defined by the contractor and JPL.

3.4.5.4 ***Response Time***. The cooler electronics shall be capable of starting transmission of the normal telemetry and the database packets less than 100 milliseconds after the receipt of the data-request command.

3.3.7 Software Requirements

3.3.7.1 ***Programming Language***. All cryocooler software shall be implemented using standard Ada (MIL-STD-1815), C (ANSI STD X3/159), or FORTRAN (ANSI STD X3.9) with the following exceptions. Nonconforming C extensions may be used to meet performance goals in the freestanding environment. Assembly language may be used where performance requirements cannot be met for time-critical functions. With the exception of programmable read-only memory (PROM) resident software, assembly language shall not be used without JPL approval. All cases where assembly language is deemed necessary shall be clearly identified.

3.3.7.2 ***Version Control***. All cryocooler software and firmware shall be implemented with an internal identifier (embedded in the executable program) that can be included in the data message. This identifier shall be keyed to the configuration management process so that the exact version of software and firmware residing in the cryocooler can be determined at any time.

3.3.7.3 ***On-Orbit Installation and Verification***. The cryocooler software shall be designed so that revisions can be feasibly installed and verified on-orbit.

3.3.7.4 ***On-Orbit Permanent Storage***. Although the cryocooler software is required to be modifiable (see 3.3.7.3), a copy of the baseline cryocooler software routines that are required to provide normal cryocooler operation (such as startup, vibration and temperature control and monitoring, etc.) shall be carried on-board in permanent storage. Upon power-up, this copy shall be utilized as a default.

3.3.7.5 ***Margin Requirements***. At the end of the Engineering Model electronics development process, the random access memory (RAM) margin shall be no less than 50%.

3.3.8 Contamination Control

3.3.8.1 ***Surface Cleanliness***. The cooler exterior shall be free from visible contamination such as scale, particles, rust, dirt, dust, grease, oil, water, and other foreign materials.

3.3.8.2 ***Surface Cleanability***. The cooler exterior shall be readily cleanable to maintain a surface cleanliness of 300 A per MIL-STD-1246. Cryocooler subassemblies that are sealed and vented with appropriate filters, such as electronic boxes, may exceed the Level 300 particulate requirement, however the Level A NVR requirement must be met. The external surfaces shall be cleanable with ethyl alcohol using standard wipe techniques. Consideration must be given to compatibility of the hardware with the cleaning agent fumes. The cryocooler shall be designed to operate in clean work areas or work stations of Class 10,000 or better per FED-STD-209.

3.3.8.3 ***Material Outgassing***. All materials that will be exposed to the space vacuum shall have a total mass loss (TML) of less than 1% and a collected volatile condensable of less than 0.1% when tested in accordance with ASTM E595-93 or equivalent method. The regain moisture loss (RML) may be subtracted from the TML. Thermal vacuum bake-out may be conducted on materials not meeting this requirement.

3.3.9 Human Performance/Human Engineering

Human performance shall be considered in the design process, material processing, testing, and all phases of design, development, and operation. Particular attention shall be given to requirements for the installation and removal of subassemblies from the cryocooler using mating connectors and any repair/replacement or maintenance procedures. MIL-STD-1472 should be used as a guide in this respect.

3.3.10 Safety

The cryocooler shall conform to the requirements of MIL-STD-882 and to the following requirements of EWR 127-1.

a. A functional analysis shall be performed to determine that the operation, interaction, or sequencing of components shall not lead to unsafe conditions, personnel injury, or major damage to the host instrument or associated ground support equipment.

b. A complete structural analysis shall be performed. The results of the structural analysis shall demonstrate safe stress levels for all components.

3.3.10.1 ***Cryocooler Safety Provisions***. The cryocooler shall incorporate provisions as necessary to protect both the cryocooler and the host S/C and instruments from cryocooler-induced damage. As a minimum, this shall include the following:

a. Automatic shut-off in the event that either coldload interface temperature is greater than 70°C

b. Automatic shut-off in the event the compressor-assembly temperature is greater than 70°C or less than -30°C

c. Automatic shut-off in the event that the compressor or other powered drive exceeds a programmable maximum limit (stroke, rpm, etc).

3.3.11 Structural Design Criteria

3.3.11.1 ***Structural Factors of Safety***. The cryocooler shall be designed with adequate margins to ensure compliance with the requirements of this specification for all mission phases using a factor of safety (FS) of 1.4 ultimate and 1.25 yield for conventional metallic materials, 2.0 ultimate and 1.4 yield for unconventional and nonmetallic materials, and 2.0 ultimate and 1.5 yield for inserts and joints. Buckling, crippling, and shear failures shall be considered as ultimate failures. These factors shall be applied to the limit load defined in 3.3.11.2 to derive yield and ultimate stresses. The stress margins of safety (MS) shall be no less than zero and shall be calculated as follows:

$$MS_{yield} = \frac{\text{Allowable yield stress or force}}{(\text{Limit stress or force}) \times FS_{yield}} - 1$$

$$MS_{ultimate} = \frac{\text{Allowable ultimate stress or force}}{(\text{Limit stress or force}) \times FS_{ultimate}} - 1$$

3.3.11.2 ***Limit Loads***. The limit load is defined as the maximum load expected to occur in service during all mission phases. For each cryocooler assembly, the limit load shall be the maximum load resulting from application of the static acceleration defined for the assembly's mass by the Mass Acceleration Curve (MAC) of Fig. 3.3.11.2-1, or by the random and sine vibration environments specified in 3.2.4.2.3 and 3.2.4.2.4, whichever is greater.

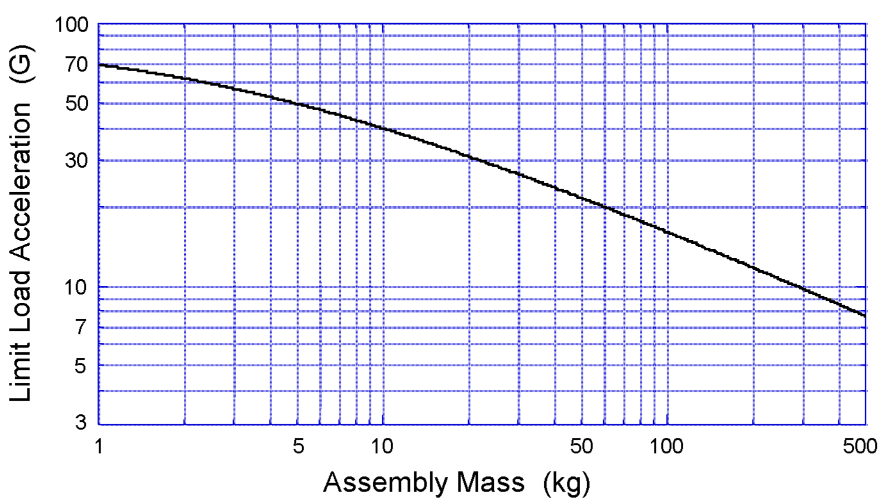

Figure 3.3.11.2-1. Mass acceleration curve for cryocooler assemblies.

3.3.11.3 ***Pressurized Components***. The cryocooler shall be designed to have adequate strength for all mission phases, per MIL-STD-1522A. The cryocooler shall be designed with a minimum analytical factor of safety of 4.0 for diameters of less than 3.8 cm (1.5 in.) or 2.5 for diameters of 3.8 cm (1.5 in.) or greater per 5.3.1 of MIL-STD-1522 for ultimate relative to the maximum operating pressure. In addition, the design shall allow the assembled cooler to be tested as specified in the applicable paragraphs of Section 5.1 of MIL-STD-1522 to demonstrate that the cryocooler meets a proof test of 1.5 times the maximum allowable working pressure.

3.3.11.4 ***Fatigue life.*** Cryocooler components shall be designed to have a fatigue life >4 lifetimes.

3.3.11.5 ***Corrosion and Fracture Control***. Cryocooler components shall be designed to prevent material degradation due to materials incompatibility, hydrogen embrittlement, or stress corrosion cracking. The design shall prevent preexisting flaws from propagating to failure under mission-induced loads, using fracture control procedures.

3.3.12 Maintainability

The cryocooler shall be designed to minimize maintenance during its ground operation and storage and shall require no maintenance during orbital operation. The contractor shall specify any maintenance necessary to achieve the storage life specified in 3.2.2.5.2.

3.3.12.1 ***Preventative Maintenance***. Preventative maintenance shall not be required at the operational level. Maintenance provisions requiring electrical trimming, mechanical adjustments, or internal alignments shall not be utilized. The mechanical cooler shall be a sealed assembly requiring no servicing of the working fluid.

3.3.12.2 ***Corrective Maintenance***. Wherever possible, the design of the cryocooler shall be directed toward minimizing the time required for corrective maintenance on the ground. In flight, corrective maintenance shall be limited to reprogramming activities directed from the ground.

3.3.12.3 ***Testability***. Access to signals to allow fault isolation between the mechanical cooler and the cooler electronics shall be provided via the primary interface connectors or optional test connectors to the maximum extent possible.

3.3.12.4 ***Fault Diagnosis***. To the extent reasonable, the cryocooler shall incorporate provisions for tracking the health of the cooler system as it proceeds through the build, test, integration, and on-orbit operational phases. Particularly important parameters are those that are critical to operation or fault diagnosis, and are difficult to measure with external instrumentation. Examples include verification of piston/shaft freedom of motion, and measurement of gas fill pressure, coldend heat load, compressor drive speed/stroke, and drive motor input current/voltage/power.

3.3.12.5 ***Interchangeability***. The cryocooler shall be mechanically, thermally, and electrically interchangeable with any other cryocooler built to the same design. The mechanical cooler and the cooler electronics from one cryocooler shall be interchangeable with the same elements from another cryocooler.

3.3.13 Design Practices

3.3.13.1 ***Use of Metric Units***. The contractor shall specify the approach to be used and the extent to which metric (SI) units of measurement will be used to meet the requirements of this specification. Use of metric units shall be assumed for new designs unless it can be demonstrated to result in significant inefficiencies.

3.3.13.2 ***Marking.*** Cryocooler parts and assemblies shall be marked per FS500451.

4. QUALITY ASSURANCE PROVISIONS

4.1 Responsibility for Quality Assurance

Primary responsibility for quality assurance of delivered hardware, processes, tests, or services is placed on the supplier, who is responsible for offering only those hardware, processes, tests, or services that conform to specified requirements. The contractor shall implement a quality assurance program to assure that the requirements of this specification are met.

4.2 Quality Conformance Inspections and Tests. The requirements of Section 3 shall be verified by one or more of the following methods as outlined in Table 4.3-1:

1. Inspection (I). A visual observation, examination, or direct measurement of the physical characteristics of the deliverable item with a comparison to the applicable requirement.
2. Analysis (A). A prediction showing that the deliverable hardware complies with the stated requirements based on measured properties including component-level development test data together with analytical models based on the applicable engineering and physical governing equations.
3. Flight Analysis (FA). A prediction showing that the proposed **flight hardware design** would comply with the stated requirements based on component-level development test data and inspections together with analytical models based on the applicable engineering and physical governing equations. However, the EM or Brassboard deliverable hardware need not satisfy the requirement.
4. Test (T). The direct measurement of applicable parameters during operation of the deliverable item under controlled conditions with test inputs and sufficient instrumentation to provide quantitative data that are directly compared to prescribed requirements.
5. EM Test (ET). The direct measurement of applicable parameters during operation of the deliverable cryocooler with **EM electronics**. This test is not applicable for the EM mechanical cryocooler with brassboard electronics.
6. Design Review (D). The determination that the requirement is met by examining the detailed design of the deliverable component or subassembly by independent technical experts not directly involved in the design itself.
7. Flight Design Review (DF). The determination that the proposed **flight hardware design** would comply with the stated requirements based on examination of the proposed flight design of the component or subassembly by independent technical experts not directly involved in the design itself. However, the EM or Brassboard deliverable hardware need not satisfy the requirement.

Table 4.3-1 Product Verification Matrix.

	EM Clr-Sys.	EM Comp.	EM Cold Hd	EM Elect.	BB Elect.	EGSE
3. REQUIREMENTS						
3.1 DEFINITIONS						
3.1.1 Modes of Operation						
3.1.1.1 Launch/Off Mode	T	D	D	D	D	
3.1.1.2 Standby Mode	T	D	D	D	D	
3.1.1.3 Cooldown Mode	T	D	D	D	D	
3.1.1.4 Normal Mode	T	D	D	D	D	
3.1.1.5 Shutdown Mode	T	D	D	D	D	
3.2 CHARACTERISTICS						
3.2.1 Physical Characteristics						
3.2.1.1 Size	FA	I	I	I	FA	
3.2.1.1.1 18K Coldhead Separation Distance	FA		I			
3.2.1.1.2 6K to 18K Coldhead Separation Distance	FA		I			
3.2.1.2 Mass	FA	I	I	I	FA	
3.2.2 Performance						
3.2.2.1 Refrigeration Performance						
3.2.2.1.1 EOL Operating Point	T	D	D	D	D	
3.2.2.1.2 Baseline Operating Point	T	D	D	D	D	
3.2.2.1.3 Minimum Operating Point	T	D	D	D	D	
3.2.2.1.4 Baseline Cooldown Starting Condition	D	D	D	D	D	
3.2.2.1.5 Cooldown Time	T	D	D	D	D	
3.2.2.2 Power Consumption						
3.2.2.2.1 Baseline Power Consumption.	ET/FA	T		FA	FA	
3.2.2.2.2 EOL Power Consumption	ET/FA	T		FA	FA	
3.2.2.3 Temperature Sensors and Control						
3.2.2.3.1 Temperature Sensors						
3.2.2.3.1.1 6K Temperature Sensors	T	D	D	D	D	
3.2.2.3.1.2 18K Temperature Sensors	T	D	D	D	D	
3.2.2.3.2 Coldload Temperature Set Point Range	T	D	D	D	D	
3.2.2.4 Temperature Stability						
3.2.2.4.1 6K Short-Term Stability	T	D	D	D	D	
3.2.2.4.2 6K Long-Term Stability	T	D	D	D	D	
3.2.2.4.3 18K Short-Term Stability	T	D	D	D	D	
3.2.2.4.4 18K Long-Term Stability	T	D	D	D	D	
3.2.2.5 Lifetime						
3.2.2.5.1 Operating Life	FA	A	A	FA		
3.2.2.5.2 Storage Life	FA	A	A	FA		
3.2.2.5.3 Start/Stop and Cooling Cycles	FA	A	A	FA		
3.2.3 Interfaces						
3.2.3.1 Structural Mounting Interfaces						
3.2.3.1.1 Compressor Assembly Mounting		D				
3.2.3.1.2 Coldhead Mounting			D			
3.2.3.1.3 Transfer Line Mounting	D					
3.2.3.1.4 Cooler Electronics Mounting				D	DF	
3.2.3.2 Cryogenic Load Interface						
3.2.3.2.1 Cryogenic Load Mechanical Interface			T			
3.2.3.2.2 Cryogenic Load Interface Flatness			I			
3.2.3.3 Heat Rejection Interfaces						
3.2.3.3.1 Compressor Heat Rejection Interface		T				

Table 4.3-1 Requirements Verification Matrix (Con't).

	EM Clr-Sys.	EM Comp.	EM Cold Hd	EM Elect.	BB Elect.	EGSE
3.2.3.3.2 Inter. Temp. Heat Rejection Interface			T			
3.2.3.3.3 Electronics Heat Rejection Interface				T	DF	
3.2.3.4 Electrical Interfaces						
3.2.3.4.1 Power Source Interface						
3.2.3.4.1.1 Input Voltage	ET/FA			T	DF	T
3.2.3.4.1.2 Power Source Impedance						T
3.2.3.4.2 Command and Data Interface						
3.2.3.4.2.1 Command Input				D	DF	D
3.2.3.4.2.2 Sync Clock Input				D	DF	D
3.2.3.4.2.3 Outputs				D	DF	D
3.2.4 Environmental Requirements						
3.2.4.1 Ground Operations and Handling						
3.2.4.1.1 Ambient Air Temperature		D	D	D	D	D
3.2.4.1.2 Ambient Pressure		D	D	D	D	D
3.2.4.1.3 Relative Humidity		D	D	D	D	D
3.2.4.2 Launch Environment						
3.2.4.2.1 Launch Temperature Range		D	D	D		
3.2.4.2.2 Atmos. Pressure Decay During Launch		A	A	FA		
3.2.4.2.3 Random Vibration		T	T	T		
3.2.4.2.4 Sinusoidal Vibration		T	T	T		
3.2.4.2.5 Resonant Frequency Stability		T	T	T		
3.2.4.3 Flight Structural/Thermal Environments						
3.2.4.3.1 Thermal Interface Temperatures	T	T	T	T		
3.2.4.3.2 Thermal Interface Temperature Stability	D	D	D	D		
3.2.4.3.3 Space Vacuum	D	D	D	D		
3.2.4.3.4 Acceleration	D	D	FA			
3.2.4.4 Space Radiation Environments						
3.2.4.4.1 Total Ionizing Dose		D	D	DF	DF	
3.2.4.4.2 Internal Charging		D	D	DF	DF	
3.2.4.5 EMI Requirements						
3.2.4.5.1 Conducted Emissions, Power Leads						
3.2.4.5.1.1 Current Change Rate	ET			D		
3.2.4.5.1.2 Turn-On Transient Current	ET			D		
3.2.4.5.1.3 Turn-Off Transient Voltage	ET			D		
3.2.4.5.1.4 Total Reflected Ripple Current	ET			D	FA	
3.2.4.5.1.5 Narrowband Cond. Emissions (CE01/CE03)	ET			D	FA	
3.2.4.5.1.6 Broadband Conducted Emissions (CE03)	ET			D		
3.2.4.5.2 Conducted Susceptibility, Power Leads	ET			D		
3.2.4.5.3 Conducted Susceptibility, Power Spike	ET			D		
3.2.4.5.4 Radiated Emissions, Magnetic Field						
3.2.4.5.4.1 Radiated AC Magnetic Field Emissions		T	T	T		
3.2.4.5.4.2 Radiated DC Magnetic Field Emissions		T	T	T		
3.2.4.5.5 Radiated Emissions, Electric Field						
3.2.4.5.5.1 Narrowband Emissions	ET			D		
3.2.4.3.5.2 Broadband Emissions	ET			D		
3.2.4.5.6 Radiated AC Magnetic Field Susceptibility	ET			D		
3.2.4.5.7 Radiated Electric Field Susceptibility	ET			D		
3.2.5 Operational						
3.2.5.1 Startup/Shutdown Conditions				T		

Table 4.3-1 Requirements Verification Matrix (Con't).

	EM Clr-Sys.	EM Comp.	EM Cold Hd	EM Elect.	BB Elect.	EGSE
3.2.5.2 Abnormal Conditions						
3.2.5.2.1 Abnormal Input Voltage	ET			T		
3.2.5.2.2 Unannounced Power Loss	ET			T	T	T
3.2.5.2.3 Unannounced Clock Signal Loss	ET			T		
3.2.5.2.4 Unannounced Digital Interface Loss	ET			T		
3.2.5.3 Autonomous Operation	D			D	DF	
3.2.5.4 Survival Configuration	T			D	D	
3.2.5.5 Operating Orientation	D	D	T			
3.2.5.6 Short Functional Test	T			D	D	
3.2.5.7 Electrical Ground Test Requirements						
3.2.5.7.1 Input Power					T	T
3.2.5.7.2 Ground Test Components					T	T
3.2.5.7.3 Ground Test Interlocks					T	T
3.3 DESIGN AND CONSTRUCTION						
3.3.1 Parts, Materials and Processes						
3.3.1.1 Materials	DF	D	D	DF	DF	
3.3.1.2 Electronic Parts				DF	DF	
3.3.1.2.1 Radiation Tolerance				DF	DF	
3.3.1.2.2 Single Event Effects (SEE)				DF		
3.3.1.2.3 Single Event Upset (SEU)				DF		
3.3.1.2.4 Single Event Latch-up (SEL)				DF		
3.3.1.2.5 Single Event Burnout and Gate Rupture				DF		
3.3.1.2.6 Operating-Limit Derating				DF	DF	
3.3.1.3 Electronic Packaging						
3.3.1.3.1 Thermal Cycle Endurance				A		
3.3.1.3.2 Min. Circuit Board Resonant Frequency				A		
3.3.1.3.3 Maximum Part Junction Temperatures				A		
3.3.1.4 Connectors						
3.3.1.4.1 Keying				D	D	
3.3.1.4.2 Connector Types				D	D	
3.3.2 Isolation, Grounding, and Shielding						
3.3.2.1 Chassis Ground	D	D	D	D		
3.3.2.2 Primary Power Isolation	ET	T	T	T		
3.3.2.3 Secondary Power Isolation	ET	D	D	T		
3.3.2.4 Motor Drive Isolation	ET	T	T	T		
3.3.2.5 Signal Conductor Shielding	D	D	D	D	D	D
3.3.3 Mechanical Design Requirements						
3.3.3.1 Minimum Resonant Frequency		T	T	T		
3.3.3.2 Compressor Self-Induced Vibration		T				
3.3.3.3 Coldhead Self-Induced Vibration			T			
3.3.3.4 Coldhead Differential Motion Capability			A			
3.3.3.5 Coldhead Applied Force Capability			A			
3.3.3.6 Caging of Cryocooler Mechanisms		T	T			
3.3.3.6.1 Ground Support Caging Devices		T	T			
3.3.3.7 Leak Rate	T	T	T			
3.3.3.8 Mechanical Cooler Thermal Cycle Endurance		A/T	A/T			
3.3.4 Thermal Design Requirements						
3.3.4.1 Coldhead Off-State Thermal Conductance			T			
3.3.5 Electrical Design Requirements						

Table 4.3-1 Requirements Verification Matrix (Con't).

	EM Clr-Sys.	EM Comp.	EM Cold Hd	EM Elect.	BB Elect.	EGSE
3.3.5.1 Power Filtering				D		
3.3.5.2 Suppression Devices				D		
3.3.5.3 Electrical Synchronization				D		
3.3.6 Command and Data Handling Req.						
3.3.6.1 Command Response				D	D	
3.3.6.1.1 Command List				D	D	
3.3.6.2 Command Constraints						
3.3.6.2.1 Toggle Commands				D	D	
3.3.6.2.2 Critical Commands				D	D	
3.3.6.2.3 Override of Auto. Triggered Functions				D	D	
3.3.6.2.4 Command Execution Verification				D	D	
3.4.5.3 Data Message Response						
3.4.5.3.1 Data Message List				D	D	
3.4.5.4 Response Time				D		
3.3.7 Software Requirements						
3.3.7.1 Programming Language				D	DF	
3.3.7.2 Version Control				D		
3.3.7.3 On-Orbit Installation and Verification				D	DF	
3.3.7.4 On-Orbit Permanent Storage				D	DF	
3.3.7.5 Margin Requirements				D		
3.3.8 Contamination Control						
3.3.8.1 Surface Cleanliness		I	I			
3.3.8.2 Surface Cleanability		D	D			
3.3.8.3 Material Outgassing		D	D	DF	DF	
3.3.9 Human Performance/Engineering	D	D	D	D	D	
3.3.10 Safety	D	D	D			
3.3.10.1 Cryocooler Safety Provisions	D	D		D	D	
3.3.11 Structural Design Criteria						
3.3.11.1 Structural Factors of Safety	A	A	A	A		
3.3.11.2 Limit Loads	A	A	A	A		
3.3.11.3 Pressurized Components	A	A	A			
3.3.11.4 Fatigue life	A	A	A	A		
3.3.11.5 Corrosion and Fracture Control	A	A	A			
3.3.12 Maintainability	D					
3.3.12.1 Preventative Maintenance	D	D	D	D		
3.3.12.2 Corrective Maintenance	D	D	D	D	DF	
3.3.12.3 Testability	D	D	D	D	D	
3.3.12.4 Fault Diagnosis	D	D	D	D	D	
3.3.12.5 Interchangeability	D	D	D	D	DF	
3.3.13 Design Practices						
3.3.13.1 Use of Metric Units	D	D	D	D		
3.3.13.2 Marking	D	D	D	D		

4.3 Test Documentation and Equipment

4.3.1 ***Test Documentation.*** Prior to the conduct of any testing called for by this specification, the contractor shall prepare a test procedure including the testing sequence, the test methods, and the pass/fail criteria for each test. The test procedure shall be submitted to JPL for approval prior to testing. Complete records of all tests shall be kept and made available to JPL. The records shall include the data for each test conducted. A JPL representative shall be notified of test dates so that tests may be witnessed by JPL.

4.3.2 ***Test Equipment Accuracies.*** Unless otherwise agreed to, equipment used to measure unit parameters shall not introduce an error greater than ten percent of the tolerance of the parameter being measured.

4.4 Cryocooler System Design and Verification Program

The following items, consisting of verification tests and analyses listed in Table 4.3-1, shall be used, as applicable, in combination with Design Reviews and Inspections to verify the requirements of Section 3. Items marked with asterisk (*) are only applicable to the EM electronics and are not applicable to the Brassboard electronics.

4.4.1 *Digital Communication and Software Functionality Test*

A Digital Communication and Software Functionality Test shall be conducted to verify the digital interface and control functionality of the cryocooler electronics and EGSE with respect to paragraphs 3.1.1 and 3.2.5 as noted below. The capability of the cryocooler to implement all applicable modes of operation specified in 3.1.1 shall be verified.

3.1.1.1	Launch/Off Mode
3.1.1.2	Standby Mode
3.1.1.3	Cooldown Mode
3.1.1.4	Normal Mode
3.1.1.5	Shutdown Mode
3.2.5.2.2	Unannounced Power Loss
3.2.5.2.3*	Unannounced Clock Signal Loss
3.2.5.2.4*	Unannounced Digital Interface Loss
3.2.5.4	Survival Configuration
3.2.5.6	Short Functional Test
3.2.5.7.1	Input Power
3.2.5.7.2	Ground Test Components
3.2.5.7.3	Ground Test Interlocks

4.4.2 *Thermal Vacuum Refrigeration Performance Test*

A system-level test of the entire cryocooler shall be conducted to verify conformance to the refrigeration performance, power consumption and heat rejection interface requirements defined in paragraphs 3.2.2.1, 3.2.2.2, 3.2.3.3 and 3.2.4.3 as described below. Capability to survive 50 thermal cycles to Protoflight non-operating temperatures may be demonstrated at the assembly level. The cryogenic heat loads shall be applied by means of heaters mounted on the thermal masses that are attached to the 6K and 18K coldload interfaces. Care shall be taken to quantify any cryogenic heat load contributions associated with coldhead radiation and structural-support parasitics.

3.2.2.1.1	EOL Operating Point
3.2.2.1.2	Baseline Operating Point
3.2.2.1.3	Minimum Operating Point
3.2.2.1.5	Cooldown Time
3.2.2.2.1	Baseline Power Consumption†
3.2.2.2.2	EOL Power Consumption†
3.2.5.5	Operating Orientation
3.2.3.2.1	Cryogenic Load Mechanical Interface
3.2.3.3.1	Compressor Heat Rejection Interface
3.2.3.3.2	Inter. Temp. Heat Rejection Interface
3.2.3.3.3*	Electronics Heat Rejection Interface

3.2.4.3.1	Thermal Interface Temperatures
3.3.4.1	Coldhead Off-State Thermal Conductance

† Only mechanical cooler input power when using Brassboard electronics

4.4.3 ***Cryocooler Temperature Control and Stability Test***

A system-level test of the entire cryocooler shall be conducted to verify conformance to the Temperature Sensors and Control and Temperature Stability requirements defined in paragraphs 3.2.2.3 and 3.2.2.4 as follows:

3.2.2.3.1	Temperature Sensors
3.2.2.3.1.1	6K Temperature Sensors
3.2.2.3.1.2	18K Temperature Sensors
3.2.2.3.2	Coldload Temperature Set Point Range
3.2.2.4.1	6K Short-Term Stability
3.2.2.4.2	6K Long-Term Stability
3.2.2.4.3	18K Short-Term Stability
3.2.2.4.4	18K Long-Term Stability

4.4.4 ***Electrical Power Interface and EMI Test***

Tests shall be conducted to verify conformance to the electrical interface and EMI requirements defined in paragraphs 3.2.3.4, 3.2.4.5, 3.2.5.1 and 3.3.2. For these tests the cooler shall be driven from a DC voltage supply with the source impedance characteristics identified in 3.2.3.4.1.2. EMI tests shall be conducted in accordance with the methods of MIL-STD-462 as listed below. For those tests conducted in accordance with the methods of MIL-STD-462, the requirements of the referenced paragraphs of this specification shall govern rather than the values listed in MIL-STD-462. Items marked with asterisk (*) are only applicable to testing the EM electronics and are not applicable to the brassboard electronics.

Paragraph	Characteristic	Test Method
3.2.3.4.1.1*	Input Voltage	
3.2.4.5.1.1*	Current Change Rate	
3.2.4.5.1.2*	Turn-On Transient Current	
3.2.4.5.1.3*	Turn-Off Transient Voltage	
3.2.4.5.1.4*	Total Reflected Ripple Current	
3.2.4.5.1.5*	Narrowband Emissions	CE01/CE03
3.2.4.5.1.6*	Broadband Emissions	CE03
3.2.4.5.2*	Conducted Susceptibility, Power Leads	CS01/CS02
3.2.4.5.3*	Conducted Susceptibility, Power Spike	CS06
3.2.4.5.4.1	Radiated AC Magnetic Field Emissions	
3.2.4.5.4.2	Radiated DC Magnetic Field Emissions	
3.2.4.5.5.1*	Radiated Narrowband Electric Emissions	RE02
3.2.4.3.5.2*	Radiated Broadband Electric Emissions	RE02
3.2.4.5.6*	Radiated AC Magnetic Field Susceptibility	RS01
3.2.4.5.7*	Radiated Electric Field Susceptibility	RS03
3.2.5.1*	Startup/Shutdown Conditions	
3.2.5.2.1*	Abnormal Input Voltage	
3.2.5.2.2*	Unannounced Power Loss	
3.3.2.2	Primary Power Isolation	
3.3.2.3*	Secondary Power Isolation	
3.3.2.4	Motor Drive Isolation	

4.4.5 ***Launch Vibration Test***

Launch vibration tests shall be conducted on each cryocooler assembly at the Protoflight level in all three axes to verify conformance of the individual cryocooler assemblies to the requirements defined in paragraphs 3.2.4 and 3.3.3. Functional performance and working-fluid leak rate shall be measured before and after the launch vibration test sequence on each assembly.

3.2.4.2.3	Random Vibration
3.2.4.2.4	Sinusoidal Vibration
3.2.4.2.5	Resonant Frequency Stability
3.3.3.1	Minimum Resonant Frequency
3.3.3.6	Caging of Cryocooler Mechanisms
3.3.3.6.1	Ground Support Caging Devices

4.4.6 ***Self-Induced Vibration Test***

Assembly-level vibration tests shall be conducted to verify conformance of the individual cryocooler assemblies to the self-induced vibration requirements defined in paragraph 3.3.3 as noted below:

3.3.3.2	Compressor Self-Induced Vibration
3.3.3.3	Coldhead Self-Induced Vibration

4.4.7 ***Cryocooler Leak Rate Test***

Leak rate tests shall be performed on the completed cryocooler after filling and before and after the principal environmental tests (4.4.2 and 4.4.5) on each assembly to verify the leak rate requirement of 3.3.3.7. The total working-fluid leakage shall be measured by mounting the compressor or coldhead assembly in a vacuum chamber and determining the total gas loss as measured by a mass spectrometer connected to the vacuum system. The test shall be conducted by a total measurement and not by a sampling measurement. The sum of the measured leak rates for all cryocooler assemblies shall be no greater than the leak rate specified in 3.3.3.7. The allowable working-fluid leak rate shall be determined by an analysis of the cryocooler internal volume and initial charging pressure.

4.4.8 ***Cryocooler Life Analysis***

A thorough analysis showing compliance with the End-of-Life (EOL) requirements of paragraphs 3.2.2.1.1 and 3.2.2.2.2 shall be performed based on component-level development and life test data, comparison with system life test data on analogous hardware, and analytical models based on the applicable engineering and physical governing equations. Specific elements of the analysis shall address the following requirements:

3.2.2.5.1	Operating Life
3.2.2.5.2	Storage Life
3.2.2.5.3	Start/Stop Cycles
4.4.5	Vibration test campaigns
4.4.2	Thermal/vacuum test campaigns
3.3.3.7	Maximum leakage of working fluid
3.3.3.8	Mechanical Cooler Thermal-Cycle Endurance

4.4.9 *Cryocooler Structural Analysis and Verification*

A thorough analysis showing compliance with the structural and safety requirements of paragraphs 3.3.11 shall be performed based on component-level finite element modeling, assembly-level test data, and other analytical models based on the applicable engineering and physical governing equations. Specific elements of the analysis shall address the requirements listed below. With respect to the pressurized components requirements in 3.3.11.3, the contractor shall conduct qualification testing as specified in the applicable paragraphs of Section 5.1 of MIL-STD-1522 and shall demonstrate that the cryocooler meets a proof test of 1.5 times the maximum allowable working pressure. These data may be acquired as part of the mechanical cooler build data.

3.3.11.1	Structural Factors of Safety
3.3.11.2	Limit Loads
3.3.11.3	Pressurized Components
3.3.11.4	Fatigue life
3.3.11.5	Corrosion and Fracture Control
3.2.4.2.2	Atmos. Pressure Decay During Launch
3.3.3.4	Coldhead Differential Motion Capability
3.3.3.5	Coldhead Applied Force Capability

4.4.10 *Electronic Packaging Structural/Thermal Analysis*

An analysis showing compliance with the electronic packaging structural/thermal requirements of paragraph 3.3.1.2 shall be performed based on component-level development and thermal-cycle life test data, comparison with the measured performance of analogous hardware, and analytical models based on the applicable engineering and physical governing equations. Specific elements of the analysis shall address the following requirements. Items marked with asterisk (*) are only applicable to the EM electronics and are not applicable to the Brassboard electronics.

3.3.1.2.1*	Thermal Cycle Endurance
3.3.1.2.2*	Minimum Circuit Board Resonant Frequency
3.3.1.2.3*	Maximum Part Junction Temperatures

APPENDIX B

General Instructions for Responding to this Technology Announcement

B.1 GENERAL PROVISIONS AND POLICIES

1. Who May Propose to the Navigator Program (NP) Advanced Cryocooler Technology Development Program (ACTDP) Technology Announcement (TA).

   This TA is restricted to U.S. qualified proposers. Qualified proposers are U.S. organizations including educational institutions, nonprofit nonacademic organizations, industry, NASA Centers including the Jet Propulsion Laboratory (JPL), and other government agencies. In accordance with Federal statutes and NASA policy, no eligible applicant shall be excluded from participation in, denied the benefits for, or be subjected to discrimination under any program or activity receiving financial assistance from NASA on the grounds of race, color, creed, age, sex, national origin, or disability. In order to determine the appropriate funding instrument in the event a proposal is selected for funding, one of the categories listed below shall be indicated on the appropriate line on the proposal cover page.

   Types of Proposing Institutions:

   Educational Institution: An accredited university or college to confer degrees (all such institutions are considered nonprofit).

   Nonprofit, Nonacademic Organization: A private or Government supported research laboratory, university consortium, museum, observatory, or similar organization that supports advanced research but whose central charter is not for training students.

   Industry: An organization of any size that operates for profit on a fee basis with capabilities and interests to conduct advanced technology development

   NASA Center: Any NASA Center organization including JPL

   Other Government Agency: Any non-NASA, U.S. Federal Executive agency, national laboratory, or Federally Funded Research and Development Center (FFRDC) sponsored by a Federal Agency.

2. A Notice of Intent (NOI) to propose is requested. The NOI is neither a commitment to submit a proposal nor is information contained therein considered binding on the submitter. NOI's may be submitted electronically by providing the information requested to the "General Point of Contract" for this TA, Mr. William D. Kert, e-mail william.d.kert@jpl.nasa.gov. For anyone without Internet access, provide the following information:

   - Reference to the ACTDP TA;
   - Technology Provider name, mailing address, phone number, and e-mail address;
   - Name(s) of institution(s) and any partnering organizations, if known by NOI due date;
   - Descriptive title of the technology

3. Proposers are requested to provide proposals that conform to the proposal content outlined in APPENDIX C.2. The ACTDP reserves the right to make awards without discussions; therefore, proposals should be as complete as possible and submitted on the proposers' most favorable terms.

4. All responses received will be reviewed for applicability and appropriateness to the TA criteria; however, it is understood that there is no commitment implied or otherwise that peer reviews will result in a procurement. Neither the Government nor JPL will be responsible for any cost incurred in furnishing this information.

5. To be considered for award, a proposal shall, at a minimum, describe an advanced cryocooler technology that addresses the technology needs described in APPENDIX A. An organization may submit proposals for more than one technology concept. Proposals should contain sufficient technical information to permit a meaningful evaluation, using the defined evaluation criteria, and be signed by an official authorized to legally bind the technology provider's institution.

6. Joint Proposals: Where multiple organizations are involved, only one of them may submit the proposal. The proposal should describe the role to be played by the other organizations and indicate the legal and managerial arrangements contemplated.

7. Cooperative/shared development (i.e., cost sharing with other activities/organizations) is permitted. If such arrangements exist, attach confirmation letters from a person with the authority to commit the organization to the arrangement (not included in the page count).

8. Questions from potential respondents and answers from the NP will be posted on the following website: http://acquisition.jpl.nasa.gov/rfp/actdp/

9. Contract Type and Funding: For organizations requiring contracts for funding, the ACTDP will fund the Study Phase through fixed-price R&D (Cost Reimbursement with Educational Institutions (CREI) for universities) contracts issued by the Jet Propulsion Laboratory (JPL)/ California Institute of Technology. Proposers that require JPL to issue a Study Phase contract shall comply with JPL's General Provisions (GPs) and Additional General Provisions (AGPs). These GPs/AGPs are available through the Internet at http://acquisition.jpl.nasa.gov/e2000.htm. If you have an access problem or, would like to receive a copy of a specimen contract you may send a message to Mr. William D. Kert, e-mail william.d.kert@jpl.nasa.gov or call (818) 354-2992.

After completion of the Study Phase and technology down-selection, the selected technology providers' organizations will be invited to negotiate new funding contracts (or other agreements) with the procurement organization at JPL.

A proposal containing a large number of exceptions or one or more significant exceptions to the General Provisions and/or Additional General Provisions may make the proposal unacceptable for evaluation. Proposers must provide a detailed explanation, including the rationale, for any exceptions taken. Proposals containing exceptions may be selected for negotiations. However; if an agreement cannot be negotiated, the proposal may be rejected.

10. Other Agreements and Funding: For NASA centers and other government agency organizations, the NP Office will establish written memoranda of agreements and administer a funds transfer through NASA Headquarters to the performing organizations.

11. Proposal Personnel: Each organization submitting a proposal shall designate a single "Key Personnel" Technology Provider who will lead the quality, direction, and content of the entire proposed technology development effort through all phases, and for the use of all awarded funds.

12. Proposal Delivery: Proposals may be mailed or hand delivered to the addresses in the TA. For hand carried proposals, the JPL Visitor Control Center is open to receive proposals only on working weekdays, between 7:30 a.m. and 4:30 p.m. The JPL Visitor Control Center will date and time stamp your proposal. Proposals are due at the time and date stated on the cover of this TA.

13. Late Proposals: Any proposal, portion of the proposal, or unrequested proposal revision received at JPL after the time and date specified on the cover page of the TA is late. Any volume of a proposal received after the time and date specified will cause the entire proposal to be late. Processing delays at the proposer's home institution or its methods of shipping do not excuse the late submission of a proposal. Late proposals will not be considered for award, except under the following circumstances:

    - JPL determines that the late receipt was due solely to a delay by the U.S. postal service for which the offeror was not responsible. Timely postmark or receipt of registered, certified, or express mail "next–day service," establishing the time of deposit, shall be evidenced.
    - JPL determines that the proposal was late due solely to mishandling by JPL after receipt at JPL, provided that the timely receipt at JPL is evidenced.
    - No acceptable proposals are received in a timely manner.

14. Withdrawal: The proposer may withdraw proposals at any time before award.

15. Proposals should not contain security classified information or depend upon access or use of security classified information or facilities for any portion of the activities.

B.2 PROPOSAL INFORMATION DISCLOSURE

Restriction on Use and Disclosure of Proposal Information. If a proposal contains proprietary information that should not be used/disclosed for any purpose other than proposal evaluation, it should be clearly marked by placing the following legend on the proposal response cover sheet:

NOTICE
"The information (data) contained in [insert page numbers or other identification] of this proposal constitutes a trade secret and/or information that is commercial or financial and confidential or privileged. It is furnished to the Government and the Jet Propulsion Laboratory/California Institute of Technology ("Institute") in confidence with the understanding that it will not, without permission of the proposer, be used or disclosed other than for evaluation purposes; provided, however, that in the event a contract (or other agreement) is awarded on the basis of this proposal, the Government or the Institute shall have the right to use and disclose this information (data) to the extent provided in the contract (or other agreement). This restriction does not limit the Government's or Institute's right to use or disclose this information (data) if obtained from another source without restriction."

B.3 PAGE LIMITS

Responses are limited to 25 pages (including figures, see Table B.3). Proposals that contain information exceeding the page limit will have the excess pages removed, and the excess pages will not be evaluated. Proposal format shall be as follows:

- Typewritten using easily readable 12 point type fonts on white 8.5x11 inch paper, in single or double columns with at least a 1 inch margin on all sides;
- Double-sided printing preferred but not required (each side counts as one page);
- Bound only with metal staples, (no cardboard or plastic covers, or permanent binders, and with an easily disassembled original copy (to enable making additional copies if needed);
- No fold out pages;
- No material submitted on electronic media, nor reference on websites needed to complete the evaluation;
- Use only metric units in the body of the proposal; and
- Strictly adhere to the page limits as follows:

Section	Page Limits
Cover Page	Not Counted
Proposal Summary	1
Table of Contents	Not Counted
Technical/Management	23
Proposed Personnel	Not Counted
References	Not Counted
Facilities and Equipment (as needed)	1
Current and Pending Support	Not Counted
Proposed Cost and Schedule	Not Counted
Resumes	Not Counted

Table B.3 Proposal Page Limits

B.4 NOTIFICATION OF SELECTION

The NP Office will notify all proposers of their selection or non-selection.

B.5 CONTRACT (OR OTHER AGREEMENT) NEGOTIATIONS AND AWARD

When the funding instrument is a contract, a acquisition representative will handle negotiations, funding, and contract execution. The proposal for the Study Phase and the resulting Study Phase Final Report will be used as the basis for negotiations. The procurement representative may request certain business data through the Technology Provider's business office and may forward a specimen contract and other information pertinent to negotiations. When the funding instrument is not a JPL contract, NASA Headquarters will handle an "other agreement" process for transferring funds to the technology providers' organization. In all cases, awards will be made to institutions, not directly to the Technology Provider.

B.6 CANCELLATION

NASA and JPL reserve the right to make no awards under this TA and to cancel this TA. NASA and JPL assume no liability for canceling the TA or for anyone's failure to receive notice of cancellation.

B.7 ATTACHMENTS

The following attachment to APPENDIX B includes essential information and supplemental instructions for proposal preparation.

a. Forms and Documents Containing Information Applicable To This TA.

ATTACHMENT B.7.a, FORMS AND DOCUMENTS CONTAINING INFORMATION APPLICABLE TO THIS TA.

The following attached forms and documents are organized into two major groupings:

1. Group A shall be completed and returned as part of your quotation or cost proposal.
2. Group B is for information purposes only in preparing your quotation/proposal.

Both A and B group attachment documents are available through the electronic address: http://acquisition.jpl.nasa.gov/e2000.htm Hard copies of the Group B documents will be mailed by request only. Note that Group B Attachments may become requirements under a JPL Contract.

NOTE TO PROPOSERS: *Only the forms and documents listed below marked* X *in the box preceding the Attachment Number are applicable.*

GROUP A – Complete and return as part of your quotation/cost proposal, as applicable:

	Attachment Number	Title and Form Number
X	A-1	Acknowledgment (form JPL 2384)
X	A-2	Cost Accounting Standards (form JPL 2842) (if over $500K)
X	A-3	Government Property Questionnaire (form JPL 0544) (if required)
	A-4	(RESERVED)
	A-5	(RESERVED)
	A-6	Notice of Total Small Business Set-Aside (form JPL 4022)
	A-7	Notice of Total Small Business Set-Aside – Modified (form JPL 4023)
	A-8	(RESERVED)
	A-9	(RESERVED)
	A-10	(RESERVED)
	A-11	(RESERVED)
	A-12	Foreign Acquisitions – Certification of Eligibility for Exemption from/Certain JPL General Provisions, Additional General Provisions, and Certifications (form JPL 2881)
	A-13	(RESERVED)
X	A-14	Past Performance (form JPL 0358)
X	A-15	Cost Element Breakdown (form JPL 0549)
	A-16	Determination of Lowest Overall Price - Time-and-Material Proposals (form JPL 0359)
	A-17	Determination of Lowest Overall Price - Labor Hour Proposals (form JPL 0363)
	A-18	Determination of Lowest Overall Price - Labor-Hour Proposals to JPL-Provided Rate Ranges (form JPL 0364)
X	A-19	Cost Elements Breakdown (Short Form) (form JPL 0549-1)

GROUP B – For information only:

Attachment Number		Title and Form Number
X	B-1	Waiver of Rights to Inventions (form JPL 62-301)
	B-2	Summary Work Breakdown Structure (no form number)
	B-3	Notice to Offerors (form JPL 2843)
	B-4	Instructions for Patent Agreement for Use in Support Service Contracts (form JPL 2844) Patent Agreement (form JPL 1929)
	B-5	Notice of Requirement of Pre-award On Site Equal Opportunity Compliance Review (form JPL 3553)
X	B-6	Requirements for A Subcontracting Plan (form JPL 0294), if applicable
	B-7	Security Requirements for a Classified Contract (form JPL 2891)
	B-8	Notice of Requirement for Affirmative Action to Ensure Equal Employment Opportunity (Executive Order 11246) (form JPL 2899)
	B-9	☐ Notice to Prospective Contractors of Requirement for an Environmental Audit of the Lease Facilities (form JPL 2896) ☐ Notice to Prospective Contractors of Requirement for an Environmental Audit of the Lease Facilities – Alternate (form JPL 2896-1)
X	B-10	Certificate of Current Cost or Pricing Data (form JPL 2496), if applicable
	B-11	Standards of Conduct and Procedures for Handling Contractor Personnel Problems, Discipline, and Separation (form JPL 4412)
	B-12	(RESERVED)
X	B-13	Claims for Exceptions to Cost or Pricing Data (form JPL 2703)
	B-14	Billing Instructions - Cost-Type Contract (form JPL 2716)
X	B-15	Billing Instructions - CREI Contract (form JPL 2717)
	B-16	Billing Instructions - Labor-Hour/Time-and-Material Contract (form JPL 2718)
	B-17	JPL Contractor Safety and Health Notification (form JPL 2885)

APPENDIX C

Technology Concept Definition Study Phase
Specific Proposal Preparation Instructions

C.1 INTRODUCTION

Proposers are expected to provide sufficient details to enable evaluation by persons who are knowledgeable of, but not necessarily specialists in, the proposed technology. Proposals shall be self-contained. That is, no knowledge of technology outside of that described in the proposal should be assumed.

Key areas of the proposal include: (1) a sufficiently detailed description of the proposed cryocooler concept and an explanation of the specific merit of the proposed cryocooler technology concept relative to the technology needs in APPENDIX A; (2) technology maturity information on the proposed cryocooler concept and the proposed approach for substantiating the predicted performance; (3) a description of the proposed Study Phase activities and their associated cost and schedule; (4) a discussion of the proposed management approach, including the management structure and the system for tracking and reporting progress; and (5) information on the requisite experience and organizational capability for development of the technology.

C.2 DETAILS OF PROPOSAL CONTENTS

All proposals should be assembled with the following parts and in the order listed:

1. Cover page that contains the following information:
   - Name of this ACTDP TA;
   - Date of submission;
   - A proposal title
   - The legal name and address of the organization and specific division or campus identification, if part of a larger organization;
   - Point of contact, mailing address, telephone number, FAX number, and e-mail address of the business office person at the technology provider's sponsoring institution;
   - Proposing Technology Provider's name and full institutional mailing address, telephone number, FAX number and e-mail address
   - Technology Provider signature and date;
   - The institutional endorsement, which requires the name and title of the authorizing institutional office, the full legal name of the proposing institution, signature of the authorizing individual, and date;
   - The designation of the type of proposing institution using the definitions in APPENDIX B; and
   - Proposed price / costs for the Study Phase.

2. Proposal Summary

- A statement summarizing the potential capability of the proposed cryocooler concept to satisfy the technology needs described in APPENDIX A.
- A brief description of the proposed cryocooler concept that summarizes its central features and predicted performance, and the proposed demonstration goals using terminology understandable to a non-specialist, and a concise statement of the proposed approach for demonstrating technology maturity.
- Pictorial material for the proposed technology that is suitable for public release

NASA or JPL may publish the proposal title, the Technology Provider's name and institution, summary description, and picture (or drawing) of every selected technology concept in a public forum. Therefore, the Proposal Summary should not include proprietary information that would preclude its unrestricted release.

3. Table of Contents

4. Technical and Management Section

a. Technical Approach

The most important aspect of the proposal is the capability of the technology concept to meet the needs of NASA astrophysics missions contained in APPENDIX A. Accordingly, proposers should fully describe their cryocooler system concept and Study Phase activities so that reviewers can assess both the potential capabilities of the concept, and the likelihood for demonstrating its performance with hardware and software deliverables by the end of the Demonstration Phase. Therefore, the technical section should include the following:

- A summary description of the proposed cryocooler concept, including;
  - Functional block diagram of the proposed cryocooler system concept
  - Conceptual layout of cryocooler system mechanical components
  - Interface geometry at the 6K and 18K coldtips, and at any intermediate temperature stages
  - Heat sink requirements, including definition of power / interface area at each stage, and sensitivity to heat sink temperature
  - Thermodynamic performance, and a discussion of how it has been calculated. Any applicable previous test results shall be discussed.
  - Conceptual layout of cryocooler system power and control electronics;
  - Both the stability of the open-loop thermodynamic system and any proposed temperature control system shall be described. Any experience with existing temperature control systems shall be described
  - Cooling efficiency at lower and higher power levels
  - Self-induced vibration sources and control approaches
  - Physical characteristics; estimated size and mass for the EM mechanical cryocooler, and also for a flight cryocooler

- Preliminary estimate of system lifetime, including identification of most critical components, and options for increasing life and reliability
- A summary of any exceptions that are requested to the APPENDIX A.5.a, ACTDP Cryocooler Detailed Specifications, or deviations from the baseline configuration described therein, and the implications of bringing the proposed cryocooler system into compliance with those specifications

- Description of the technical merit of the proposed technology relative to the needs of future astrophysics missions listed in APPENDIX A;
- Expected capability of the proposed technology to benefit multiple future astrophysics missions;
- Description of the current maturity of the proposed technology and the technology maturity level expected at the end of the Study Phase. Explain how these determinations were derived;
- Discussion of the significant technical challenges to be overcome;
- Explanation of the technology development approach including major technical milestones and any special materials, parts or process needed;
- Description of the technology demonstration approach, with hardware and software deliverables, to substantiate the predicted performance;
- Description of proposed Study Phase activities and their associated cost and schedule.

b. Management Approach

This section shall summarize the management approach and the facilities and equipment required. The management approach should describe essential management functions, and the overall integration of these functions to assure adequate control of the proposed effort within the cost and schedule constraints. This section shall provide insight into the organizations proposed to do the work, including the internal operations and lines of authority, together with internal interfaces and relationships with NASA, any team members, major subcontractors, and associated collaborators. It also identifies the institutional commitment of all team members, and the institutional roles and responsibilities. Proposers shall define the management approach and tools for controlling cost and schedule best suited for their particular teaming arrangement. Proposers should also have a Work Breakdown Structure (WBS) that best fits its organizational approach and technology development capabilities of all team members. The use of innovative processes, techniques, and activities to accomplish their plans is encouraged if cost, schedule, and technical improvements can be demonstrated.

Proposals that include teaming arrangements, partnering and/or contributions to meet the technology development / demonstration objectives shall specifically address how the proposed team will interrelate internally and with NASA, both organizationally and managerially. The capabilities that each member organization brings to the team, as well as previous experience with similar systems and equipment shall also be addressed.

The management section should include the following:

- Approach for managing Study Phase activities including the work breakdown structure, a schedule, and the proposed organizational structure;
- Identify the roles and responsibilities for each participating organization and key individuals
- Approach for securing any proposed technology development collaborations
- Assumed funding contributions by technology development collaborations or partnering arrangements with other individuals or organizations not included in the proposed funding;
- If applicable, the plan for managing the distribution of responsibilities and arrangements for ensuring a coordinated team effort capable of effectively carrying out the proposed technology development / demonstration activity;
- Basis and justification for the cost and schedule estimates for Study Phase and Demonstration Phase activities;
- Expected contribution/commitment by the Technology Provider and his/her parent organization to the proposed technology development effort (include cost and resource sharing, partnering arrangements, etc.);
- Technology Provider’s historical experience, performance, and institutional capability in the area of technology development and subsequent application.

5. Proposed Personnel. Submit a one-page resume for each of the key personnel who will support the proposed effort (not included in page count).

6. Copy of References. All referenced papers cited in the proposal shall be provided as an attachment to the proposal. For book citations, provide a copy of the relevant pages and the full title of the book and/or an easily understood abbreviation of the publication (e.g., library standard citation or AIAA format) (the copies of reference papers and book references are not included in the proposal page count).

7. Facilities and Equipment. This section should describe any facilities (including any U.S. Government owned facilities) and/or test or experiment equipment that are critical for carrying out the proposed Study Phase. Discuss the availability of these special facilities and equipment items and any additional equipment or facilities that will be required. Costs shall be included in the proposal Budget Summary. Provide written substantiation (not included in the page count) from the government or other source showing concurrence with the proposed use.

8. Current and Pending Support. Briefly describe any current or planned sources of support that will be contributing to the proposed cryocooler technology activity. Identify the ongoing and pending projects, sponsoring organization, relevance to the proposed technology, and the resources each organization will contribute or share (not included in page count).

9. Proposed Cost and Schedule. (not included in page count)

   a. Proposed Study Phase Cost: Provide a one-page cost summary indicating the funding requirements for the Study Phase. Provide an explanation of the proposed funding arrangements. Examples include: ACTDP funds all study costs; proposer shares study costs with ACTDP; or proposer funds all study costs.

      The Study Phase Cost Proposal shall be submitted per the requirements of the ACTDP Study Phase Statement of Work and Delivery Schedule (APPENDIX C.4.a) per the instructions in APPENDIX C.4.b.

   b. Estimated Demonstration Phase Cost: Provide a one-page cost summary indicating the anticipated funding requirements for the Demonstration Phase. This non-binding ROM estimate when combined with the Study Phase cost should reflect the total estimated cost to demonstrate the capabilities and performance of the proposed cryocooler concept. Provide an explanation of the proposed funding arrangements.

      Also provide a separate ROM estimate of the cost to develop a set of EM electronics.

   c. Proposed Schedule: Provide a detailed schedule of the proposed Study Phase activities leading to delivery of the Study Phase Final Report. Also provide a one-page preliminary schedule for Demonstration Phase activities that identifies the major milestones leading to delivery of the EM cryocooler system. Assume the Study Phase start date given in the ACTDP TA.

C.3 PROPOSAL EVALUATION CRITERIA

Listed below are the principal criteria and their relative importance for evaluating cryocooler technology concepts for Study Phase selection. Within each criterion, factors are of equal importance.

T1 - Technical Merit And Benefits To Future Astrophysics Missions (30%): Evidence of technical merit, and feasibility of cryocooler concept to meet the needs of future astrophysics missions. Factors to be considered are:

A. Relevance, value, and benefits of the proposed cryocooler concept toward meeting OSS technology needs, including specific science mission applications.
B. Potential for providing the capabilities, and achieving the performance requirements described in APPENDIX A.
C. Degree to which multiple astrophysics missions can use the proposed technology.

T2 - Technology Maturation (30%): Credibility of the proposed technology demonstration plan and the soundness of the approach for substantiating the predicted performance. Factors to be considered are:

A. Current maturity of the proposed cryocooler technology and strength of the evidence to show how this maturity has been derived or verified.
B. Soundness of the proposed technology development approach to assure successful completion of the Study and Demonstration Phases.
C. Adequacy of the testing planned to demonstrate that the hardware and software deliverables have indeed attained the required performance at the completion of the Demonstration Phase.

M1 - Management and Implementation Approach (30%): Thoroughness and credibility of the proposed approach to implementation, including the management structure, schedule realism, level of detail and basis of cost estimate. Factors to be considered are:

A. Effectiveness of the organizational structure to carry out the proposed management plan for the end-to-end design, development, and demonstration effort, including identification and availability of key personnel.
B. Realism and reasonableness of the proposed cost, including contribution assumptions, to complete all design, development, and demonstration activities.
C. Realism and reasonableness of the proposed schedule for design, development, and demonstration activities, and the effectiveness of the system for tracking progress.

M2 - Capabilities of the Provider Organization (10%): Degree to which the technology provider has the requisite experience and organizational capability and commitment to deliver the proposed cryocooler technology concept. Factors to be considered are:

A. Experience of the Technology Provider and organizational capability to deliver cryocooler technology hardware/software.
B. Historical performance for technology development and subsequent application.
C. Commitment of the organization’s management to the proposed technology development.

C.4 ATTACHMENTS

The following APPENDIX C Attachments include essential information and supplemental instructions for proposal preparation.

a. ACTDP Study Phase Statement of Work and Delivery Schedule

b. ACTDP Study Phase Cost Information Instructions

ATTACHMENT C.4.a ACTDP STUDY PHASE STATEMENT OF WORK AND DELIVERY SCHEDULE

STATEMENT OF WORK AND DELIVERY INSTRUCTIONS

1.0 ACTDP Study Phase awardees shall conduct a Cryocooler Technology Concept Definition Study Phase (“Study Phase”), and complete the preliminary design of an EM Cryocooler system that corresponds to the specifications in the ACTDP TA APPENDIX A. The EM Cryocooler system preliminary design shall be documented in a Study Phase Final Report, per the instructions in APPENDIX E. In addition, awardees shall provide informational and other support to the ACTDP.

2.0 Schedule of Deliverables:

Deliverable	Schedule	Description (see paragraphs below for details)
Monthly Progress Report	Monthly	Telecon / e-mail discussion of progress, overall status, issues, problems, and proposed solutions
Kickoff meeting	2 weeks ARO*	At contractor’s site; introduce key personnel, discuss planning for contract
Mid-Term Study Phase Progress Review	3 months ARO	At contractor’s site, review initial cryocooler design, and development / demonstration plans
Preliminary Design Review	5 mo ARO	At a NASA site, design presentation to user community on proposed cryocooler system
Study Phase Final Report	6 mo ARO	Detailed description of the preliminary design for a ACTDP cryocooler, tradeoffs, conceptual design of EM electronics, Demonstration Phase technical, management, and cost plans

** ARO – After Receipt of Order*

2.1 Kickoff meeting

A kickoff meeting will be held at the contractor’s site to introduce key personnel, and discuss plans for establishing management and contract relationships.

2.2 Monthly Progress Reports

Study Phase awardees shall provide monthly teleconference and electronic progress / status reports to review overall progress, status, issues, problems, and proposed solutions.

2.3 Mid-Term Study Phase Progress Review

A Mid-term Study Report (in vu-graph form) and oral presentation at the contractors site shall be provided to review the initial design for an EM cryocooler, and corresponding preliminary development and demonstration plans.

2.4 Preliminary Design Review

The Preliminary Design Review shall be held at GSFC or JPL as a forum open to the Con-X, NGST and TPF science and engineering communities, with the intent of allowing the broadest possible discussion of system-level issues associated with the proposed cryocooler. The presentation shall cover the material required for the Study Phase Final Report.

Proprietary data may be presented separately, and shall be handled in accordance with the terms and conditions of the contract. Items related only to the manner of integration of the cryocooler system into a specific mission, such as heat sink loads and vibration analysis, and not to any manufacturing technology for the cryocooler, shall not be construed as proprietary.

2.5 Study Phase Final Report

Technology Providers shall deliver a Study Phase Final Report per the instructions given in APPENDIX E. The complete three volumes Study Phase Final Report will constitute the Technology Providers' Demonstration Phase proposal. As such this report should fully describe the following:

2.5.1 The proposed cryocooler preliminary design (i.e. specifically what is to be built and how well it is predicted to meet the requirements given in APPENDIX A);

2.5.2 The Demonstration Phase Technical Plan for completing the EM cryocooler system design, and building and testing it to assess the technology's capabilities and potential performance; and

2.5.3 A Demonstration Phase Management And Cost Plan that clearly describes what is required to successfully implement the Demonstration Phase Technical Plan

ATTACHMENT C.4.b ACTDP STUDY PHASE COST INFORMATION INSTRUCTIONS

This portion of the proposal instructions outlines the requirements to be followed in submitting cost information. Submit the information requested by the following instructions.

1. DATA SUBMITTAL

Provide a total price for the Study Phase Statement of Work (APPENDIX C.4.a.) and the applicable supporting data requested below.

a. Price or Cost Breakdown.

(1) For proposals up to but not exceeding $550,000.00, provide the information requested on APPENDIX B, Attachment B.7.a item A-19, Cost Elements Breakdown (Short Form). Proposers may provide the requested information, as applicable, on an alternate computer-generated form.

(2) For proposals greater than $550,000.00, provide the information requested on APPENDIX B, Attachment B.7.a item A-15, Cost Elements Breakdown. Proposers may provide the requested information, as applicable, on an alternate computer-generated form.

b. Request for Exception

For each item included in the proposal for which the price is based on catalog or market prices, prices set by law or regulation, or is on an active Federal Supply Schedule or other Government Contract, state the basis of the price and provide appropriate reference documentation. If the item is priced at an amount greater than $550,000.00, a written request for an exception to the submission of certified cost or pricing data in accordance with APPENDIX B, Attachment B.7.a item B-13, "Claims for Exceptions to Cost or Pricing Data," is required.

c. Identify the sources of funding and amounts to be provided by partners.

Note: refer to APPENDIX B.7.a regarding all additional forms and documents required in the proposal

APPENDIX D

Process for Cryocooler Technology Concept Selection

D.1 EVALUATION AND SELECTION PROCESS

The NP will use a technical peer review process to evaluate proposed technology concepts for the ACTDP Study Phase and again later to evaluate Study Phase Final Reports for down-selecting cryocooler technology concepts for the Demonstration Phase.

All proposals will initially be screened to determine their suitability and responsiveness to the TA. Proposals that are not in compliance with the constraints, requirements, and guidelines of this TA will be handled as technical correspondence and returned to the proposer without further review. Those proposals deemed responsive to the TA will then be reviewed to determine if any government, national laboratory, or FFRDC response duplicates and directly competes with a response from industry, a university or a nonprofit organization. If such a situation exists, the government, national laboratory, or FFRDC proposal will not be evaluated and will be returned to the originator.

After the screening process, proposals will be reviewed by a panel composed of the proposer's professional peers, who will evaluate the strengths and weaknesses of the technical and management information provided. The peer review panel will develop findings, and a final consensus evaluation and selection recommendation for each proposal. A programmatic review panel will also evaluate the relevance, value, and benefits of the proposed cryocooler concept toward meeting OSS technology needs, including specific science mission applications. The recommendations of these two panels will be provided to the NASA HQ executive who will select technology concepts for ACTDP funding. The NP Manager will provide notice of selections and make awards.

In the Study Phase, each technology provider will be required to produce a detailed Study Phase Final Report that fully describes their cryocooler concept, and the plan to demonstrate its potential capabilities and performance in the ACTDP Demonstration Phase. At the end of the study phase, technology providers will present their cryocooler design at a Preliminary Design Review (PDR). The PDR and accompanying Study Phase Final Report that includes a cost and management volume as described in APPENDIX E, will serve as the primary basis for approval to proceed to the ACTDP Demonstration Phase. The review and selection processes used for Study Phase proposal evaluations will be repeated for evaluating Study Phase Final Reports and making down-selections for the Demonstration Phase. Candidates for the Demonstration Phase will be limited to technology providers that provide an ACTDP Study Phase Final Report.

D.2 SCHEDULE

Study Phase Proposals Due	Date specified in TA
Study Phase Selections Announced	+8 wks after above
Study Phase Final Reports Due	+6 mo after above
Demonstration Phase Selections Announced	+4 wks after above

APPENDIX E

Cryocooler Technology Concept Definition
Study Phase Final Report Instructions

E.1 ACTDP STUDY PHASE FINAL REPORT CONTENT INSTRUCTIONS

The primary output from the ACTDP Study Phase will be a final report that describes the cryocooler technology concept and the plan to build and test an EM cryocooler system for the assessment of the technology's capabilities and potential performance.

The ACTDP Study Phase Final Report shall have three volumes: (1) EM Cryocooler Detailed Preliminary Design, (2) Demonstration Phase Technical Plan, and (3) Demonstration Phase Management and Cost Plan. The cryocooler preliminary design and Demonstration Phase technical plan volumes shall be non-proprietary and available to the Con-X, NGST, TPF and other NASA science and engineering communities to allow the broadest possible discussion of system-level issues associated with the proposed cryocooler. Proprietary data may be presented separately, and shall be handled in accordance with the terms and conditions of the study contract (or agreement). Items which are related only to the manner of integration of the cryocooler into the target application mission / system, such as heat sink requirements and vibration analysis, and not to any manufacturing technology for the cryocooler, shall not be construed as proprietary.

The Demonstration Phase management and cost plan volume may be proprietary.

1.0 Cryocooler Detailed Preliminary Design Volume Contents

The detailed preliminary design volume shall fully describe the design of the EM Cryocooler system concept including the following:

1.1. Cryocooler Preliminary Design

- 1.1.1. Layout of the EM mechanical cryocooler system components.
- 1.1.2. Block diagrams and layout of the brassboard electronics for the EM mechanical cryocooler. Identify functions and components needed to support long-term life testing of the mechanical cryocooler.
- 1.1.3. Detailed assembly drawings of major subassemblies.
- 1.1.4. Interface geometry at the 6K and 18K coldtips, and at any intermediate temperature stages.
- 1.1.5. Heat sink requirements including definition of power / interface area at each stage and sensitivity to heat sink temperature. If the compressor is designed to use a heat sink temperature other than the preferred value given in the APPENDIX A ACTDP Cryocooler Detail Specifications, the expected system benefits shall be described in detail.
- 1.1.6. Thermodynamic performance and a discussion of how it has been calculated. Any applicable previous development test results shall be discussed.
- 1.1.7. Design assumptions, operational considerations, and design margins discussion.
- 1.1.8. Vibration isolation, thermal isolation brackets for distributed plumbing, or any other thermal/mechanical details which will impact system cost or performance

1.1.9. Baseline mass and power budget for the EM cryocooler system, and an estimate of the mass and power budget for a FM.
1.1.10. Preliminary FM system lifetime analysis, including identification of most critical components, and options for increasing life and reliability.
1.1.11. Identification of any EMI concerns, major open design and development issues, trade studies, problems, and plans for their resolution in the Demonstration Phase.

1.2. System Tradeoffs

Describe the design trade-offs and alternative configurations that were examined in sufficient detail to explain why the selected configuration is preferred. Quantify the impact of the temperature of the Intermediate Temperature Stage on the mass and power requirements of the cryocooler system. Discuss the tradeoffs of using a passive radiator versus an auxiliary cryocooler at this stage.

1.3. Temperature Control

Both the stability of the open-loop thermodynamic system and any proposed temperature control system shall be described. Any experience with existing temperature control systems shall be described.

1.4. Efficiency at Lower and Higher Power Levels

In order to perform over the complete mission from BOL to EOL the cryocooler must be able to operate efficiently over the broad range of heatsink temperatures and cryogenic loads as defined in the APPENDIX A.5.a, ACTDP Cryocooler Detailed Specifications. The sensitivity of the system's cooling capacity and efficiency to the applied input power and heat sink temperature shall be quantified. The ability of the cryocooler to operate efficiently over the entire range from the EOL Operating Point to the Minimum Operating Point shall be discussed as well as the ability of the cryocooler to operate with cooling loads up to 50% below and above this range given the same heatsink temperature restrictions and a larger total power allocation. Also, discuss the ease to which the proposed design could be scaled to higher or lower power levels at the beginning of the flight build phase.

1.5. Vibration Sources and Control

Any elements of the system that may cause vibration, whether by mechanically or thermally induced motion, shall be identified. The magnitude of the vibration forces shall be estimated, and any need for vibration control or isolation shall be discussed, as well as any previous measurements which might be applicable. Any vibration control or isolation hardware required shall be described, including a description of how this would be included in the EM system. A description of how the self-induced vibration of the EM cryocooler will be measured shall be provided.

1.6. Electronics Conceptual Design

The conceptual design of the FM electronics shall be provided, including block diagrams, performance assumptions, identification of critical components, location of the electronics relative to the mechanical cryocooler, and preliminary electronic packaging design. Describe the implementation of EM electronics, including the differences with the FM implementation and the level of breadboard development needed during the Demonstration Phase.

1.7. Recommended Changes to the ACTDP Cryocooler Detailed Specifications

Provide recommended ACTDP Cryocooler Detailed Specifications revisions, updates or augmentations, for both the EM cryocooler system deliverables under this contract, and for future flight cryocooler systems. Include rationale for your recommendations.

2.0 Demonstration Phase Technical Plan Volume Contents

The ACTDP Demonstration Phase will encompass the detailed design, fabrication, test and evaluation, and delivery of the proposed EM cryocooler system. The ACTDP Demonstration Phase Technical Plan volume shall include the following:

2.1. EM Cryocooler System Development Plan

Describe the steps planned to complete the EM mechanical cryocooler system design and the brassboard electronics. Discuss the development approach that will be used to acquire / produce, integrate, and test the hardware and software deliverables, including all ground support equipment. Provide a description of the main processes/procedures planned for design validation, and hardware and software development, including testing strategy.

Also provide an option for delivering a second build-to-print EM mechanical cryocooler and brassboard electronics, and associated ground support equipment. This shall be a separate costed option to the EM cryocooler system development plan, with a separate schedule.

2.2. EM Electronics (EM Version of Flight Electronics) Development Plan

Describe the plan for developing the preliminary design of the cryocooler EM electronics. Discuss the development approach that would be used to acquire / produce, integrate, and test the hardware and software deliverables, including all ground support equipment. Provide a description of the main processes/procedures planned for design validation, (i.e. breadboarding high risk elements of the design, such as the compressor power drivers), and hardware and software development, including testing strategy.

Provide an option to develop a set of EM electronics as a separate costed option to the EM cryocooler system development plan, with a separate milestone schedule.

2.3. EM Cryocooler Analysis and Test Program

In APPENDIX A.5.a, the ACTDP Cryocooler Detailed Specification, Section 4 lists the major analysis and tests required to characterize the cryocooler. The approach for completing these analysis and tests and obtaining the data shall be described. The individual cost for each major analysis and test (items 4.4.1 through 4.4.10) shall be provided in the Demonstration Phase management and cost plan volume.

Any test facilities which must be constructed for this program shall be identified, along with the facility development schedule necessary to meet the overall EM delivery schedule.

2.4. Schedule

A detailed schedule of development and test activities shall be provided that identifies the major milestones leading to the delivery of the EM cryocooler system. Also, a preliminary schedule showing the earliest likely date for delivering a flight cryocooler system shall be provided.

3.0 Demonstration Phase Management and Cost Plan Volume Contents

The ACTDP Study Report Demonstration Phase Management And Cost Plan volume shall describe the management approach, tools and processes that will be used to complete the cryocooler technology concept demonstration, within the proposed cost and schedule.

3.1. Organizational Structure

Describe the organizational structure proposed to carry out the Demonstration Phase activity. Identify the organizational roles, authority, and responsibilities of each participating organization. Provide insight into each organizational element's internal operations and lines of authority, together with internal interfaces and relationships with NASA, any team members, major subcontractors, and associated collaborators / partners.

Identify the specific decision-making processes to be used, and the individual with ultimate decision-making authority. Specifically, include the applicable capabilities that each partner or proposed partnering organization expects to contribute. Identify key personnel in each organization. Describe the distribution of responsibilities and arrangements for ensuring a coordinated team effort capable of effectively managing the Demonstration Phase activity.

Include a discussion of the unique or proprietary capabilities that each member organization brings to the activity. The contractual and financial relationships between partners should be discussed. Summarize the relevant institutional experience and organizational capability with reference to supporting what is offered in any letters of endorsement.

3.2. Resource Management Methods and Tools

Describe the methods and tools that will be used for tracking progress towards technical milestones, and for tracking / assessing cost and schedule status. Provide a description of the Work Breakdown Structure (WBS) and how it best fits its organizational approach and technology development capabilities of all team members. A sample WBS is provided in APPENDIX E.4.b.

Provide information on procurement of long lead items and proposed major and critical subcontracts, including procurement activities of all team partners. Describe the relationships and controls that will be exercised over suppliers and subcontractors from both cost and schedule standpoints.

3.3. Risk Management

Describe the plans for risk management, and the approach for identifying and mitigating development, performance, schedule, and cost risks. Particular emphasis shall be placed on describing how the various elements of risk will be managed to ensure successful accomplishment of the demonstration phase within the proposed cost and schedule.

3.4. Product Assurance and Safety

Describe the plans to ensure product quality, including specific reviews, identification of trade studies, plans to incorporate new technologies, problem/failure resolution, inspections, quality assurance, reliability, parts selection and control, and software validation activities.

In addition, describe the process by which safety standards are met and hazards mitigated.

3.5. Cost Estimate, and Funding Assumptions and Requirements

Identify the funding required to implement the Demonstration Phase Technical Plan. Provide an explanation of the proposed funding arrangements including:

3.5.1. Provide a cost summary of the proposed funding requirements for the Demonstration Phase indicating the funding required from the ACTDP and any cost sharing arrangements. Include separate cost summaries for (a) the option to deliver a second build-to-print EM cryocooler system, and (b) the option to develop a set of EM electronics.

3.5.2. Describe any assumed funding contributions by technology development collaborations or partnering arrangements with other individuals or organizations not included in the proposed ACTDP funding;

3.5.3. Basis and justification for the cost and schedule estimates for Study and Demonstration Phase activities;

3.5.4. Expected contribution/commitment by the Technology Provider and his/her parent organization to the proposed technology development effort (include cost and resource sharing, partnering arrangements, etc.);

3.5.5. Current and Pending Support. Briefly describe any current or planned sources of support that will be contributing to the proposed cryocooler technology activity. Identify the ongoing and pending projects, sponsoring organization, relevance to the proposed technology, and the resources each organization will contribute or share (not included in page count).

The Demonstration Phase Cost Plan shall be submitted per the requirements in APPENDIX E.4.c, for the Cryocooler Technology Demonstration Phase Statement of Work and Delivery Schedule in APPENDIX E.4.a.

3.6. Furnished* Property, Services, Development Facilities, etc.

This section shall delineate the property, services, technology development facilities, etc. to be furnished by the Government or a commercial source, if any, which will be required to accomplish all proposed Demonstration Phase activities. Discuss the availability of these special facilities and equipment items and any additional equipment or facilities that will be required. Costs shall be included in the proposal Budget Summary. Provide written substantiation from the government or other source showing concurrence with the proposed use. This could be an approval letter from the cognizant government contracting officer or an equivalent commercial agent for the use of the property, service, or facilities.

*(*Provided by other than subcontract or purchase order)*

3.7. Reporting and Reviews

Describe the approach planned for reporting technical status / progress to the ACTDP. Also, discuss the methods of reporting integrated cost, schedule, and technical performance. Identify the individual or organization function responsible for reporting.

3.8. Plans to Resolve Open Management Issues

Identify and discuss any unresolved issues. Include the planned approach and schedule for resolving these issues.

E.2 ACTDP Study Phase Final Report Submission Instructions

The Study Phase Final Report will constitute the technology providers' Demonstration Phase proposal. This section provides guidelines for the preparation and submittal of the Study Phase Final Report and required supporting information.

a. Certification - The original copy of the Study Phase Final Report shall be accompanied by a Letter of Commitment signed by an official of the providing organization. This official shall certify institutional support and sponsorship for the technology concept, its technical demonstration plan, and the associated management and financial proposal.

b. Quantity & Address - Fifteen (15) copies of the Study Phase final report shall be submitted to the following address:

   Mr. William D. Kert
   Jet Propulsion Laboratory
   4800 Oak Grove Drive, M/S 190-220
   Pasadena, California 91109-8099

c. All Study Phase material shall arrive at JPL by 3:00 p.m. local time before September 30, 2002

E.3 ACTDP STUDY PHASE FINAL REPORT EVALUATION CRITERIA AND FACTORS

The following criteria and degree of importance will be used to evaluate Demonstration Phase Proposals.

Technical Criteria

T1 - Technical Merit And Benefits To Future Astrophysics Missions (30%): Evidence of technical merit, and feasibility of cryocooler concept to meet the needs of future astrophysics missions. Factors to be considered are:

A. Relevance, value, and benefits of the proposed cryocooler concept toward meeting OSS technology needs, including specific science mission applications.
B. Potential for providing the capabilities, and achieving the performance requirements described in APPENDIX A.
C. Degree to which multiple astrophysics missions can use the proposed technology.

T2 - Technology Maturation (30%): Credibility of the proposed technology demonstration plan and the soundness of the approach for substantiating the predicted performance. Factors to be considered are:

A. Current maturity of the proposed cryocooler technology and strength of the evidence to show how this maturity has been derived or verified.
B. Soundness of the proposed technology development plan to assure successful completion of the Demonstration Phase objectives.
C. Adequacy of the testing planned to demonstrate that the hardware and software deliverables have indeed attained the required performance at the completion of the Demonstration Phase.

Management Criteria

M1 - Management and Implementation Approach (35%): Thoroughness and credibility of the proposed technology development and demonstration plan, including the management structure, schedule realism, level of detail and basis of cost estimate. Factors to be considered are:

a. Effectiveness of the organizational structure to carry out the proposed management plan for the development and demonstration effort, including identification and availability of key personnel.
b. Effectiveness of the proposed management plan to structure relationships between different elements of the proposer's team that provide funding support such that a single management voice exercises decision authority.
c. Realism and reasonableness of the proposed cost, including contribution assumptions, to successfully complete all development, and demonstration activities.
d. Realism and reasonableness of the proposed schedule for development, and demonstration activities, and the effectiveness of the system for tracking progress.
e. Efficacy of the approach for identifying and managing significant risks, including the associated mitigation approaches and descope options.

M2 - Capabilities of the Provider Organization (5%): Degree to which the technology provider has the requisite experience and organizational capability and commitment to deliver the proposed cryocooler technology concept. Factors to be considered are:

A. Experience of the Technology Provider and organizational capability to deliver cryocooler technology hardware/software.
B. Historical performance for technology development and subsequent application.
C. Commitment of the organization's management to the proposed technology development.

Proposals will be evaluated in the areas of technical and management as described above. Although cost will not be scored, cost is a substantial factor and is of approximately equal importance to the technical and management areas. Low cost, while desirable, does not offset the importance of realism and reasonableness of the proposed cost. Proposal selection will be based on the offeror whose proposal is determined to represent the best value based on the following: If all offers, in the competitive range, are of approximately equal qualitative (technical and management) merit, the offer with the lowest cost will be selected. However, a proposal may be selected that offers a higher qualitative merit if the difference in cost is commensurate with added value. Conversely, a proposal may be selected that offers a lower qualitative merit if the cost differential between it and other offers so warrants.

Some of the best value characteristics that would apply include:

- The degree to which the cryocooler concept can make progress from the baseline requirements to the goals identified in the detail specifications (i.e. mass, power consumption, 18K coldhead separation distance, coldload temperature set point range, etc.)
- Lower input power than specified, for same cooling power
- Compressor module can be operated at T<100K
- Design for ease of breaking apart into subsections for system integration and test, including documented experience with cleanup of the gas loop
- Existing breadboard / laboratory hardware with cooling power between 50-200% of the specified cooling power and meets ACTDP specifications for input power and heat rejection/radiator interfaces
- Cooling power can be throttled over a range of 30-100% of the baseline operating point
- Cooling power at 6K is scalable up 15mW, with proportional increase in input power
- The cryocooler is capable of providing 5mW at 4K
- Shorter schedule for demonstration phase leading to delivery of an EM cryocooler
- Ability to use an existing flight cryocooler system to eliminate the need for the Intermediate Temperature Stage

E.4 ATTACHMENTS

The following APPENDIX E Attachments include essential information and supplemental instructions for proposal preparation.

a. Cryocooler Technology Demonstration Phase Statement of Work and Delivery Schedule
b. Cryocooler Technology Development Sample Work Breakdown Structure
c. Cryocooler Technology Demonstration Phase Cost Plan Instructions
d. Supplemental Information

ATTACHMENT E.4.a ACTDP CRYOCOOLER TECHNOLOGY DEMONSTRATION PHASE STATEMENT OF WORK AND DELIVERY SCHEDULE

STATEMENT OF WORK AND DELIVERY INSTRUCTIONS

1.0 Demonstration Phase participants shall complete the design, development, testing, and delivery of their proposed EM Cryocooler system. In addition, the Technology Provider's organization shall provide informational and other support including reports and reviews presented to ACTDP and NASA HQ (e.g., Quarterly Governing Program Management Council Reviews, etc.).

2.0 Schedule of Deliverables:

Deliverable	Schedule	Description (see paragraphs below for details)
Monthly progress report	Monthly	Telecon and E-mail discussion of progress, status, issues, problems, and resolution plans
Demonstration Phase Kick-off Meeting	1 mo ARO	At contractor's site, review action items and outstanding issues from the Study Phase PDR
Demonstration Phase Delta PDR	+2 mo after above	At contractor's site, review the disposition of action items / issues from the Kick-off Meeting
Technical Interchange Meeting #1	+4 mo after above	Review of progress against plans, major issues, problems and resolution plans
Critical Design Review	+4 mo after above	Presentation of the EM cryocooler system final design, build-to-specifications, and test plans
EM Test Plan Pre-Test Review	+4 mo after above	Review EM system test plans, assess readiness of cryocooler system and required test facilities to begin testing; subject to ACTDP concurrence
Technical Interchange Meeting #2	+4 mo after above	Review progress / results, major issues, problems and resolution plans
Technical Interchange Meeting #3	+4 mo after above	Review progress / results, testing, major issues, problems and resolution plans
Technical Interchange Meeting #4	+4 mo after above	Review progress / results, testing, major issues, problems and resolution plans
System Test Report	+4 mo after above	Final report on test configurations, results, and analysis of cryocooler testing / characterization
Acceptance Data Package	+4 mo after above	Report on as-built configuration information such as drawings, schematics, test set-ups, etc.
Pre-Ship Review	Same as above	Validate readiness of cryocooler system, and GSE to be shipped to a NASA site
EM Cryocooler System	+2 wks after above	EM cryocooler and all associated electronics, ground support equipment, etc.
FM Cryocooler Development Plan	Same as above	Technical specifications, development plan, and management and cost plan, for delivering a FM cryocooler system

* *ARO – After Receipt of Order*

2.1 Monthly Progress Reports

Monthly teleconference and electronic progress / status reports shall be provided to review technical progress, cost and schedule status, issues, problems, and proposed solutions.

2.2 Demonstration Phase Kick-off Meeting

The Demonstration Phase Kick-off Meeting, to be held at a NASA site, will review the open action items and outstanding issues from the Study Phase PDR. The purpose is to assure that any changes recommended or made will improve the cryocoolers' design towards meeting the needs of OSS Astronomy and Physics Division missions. Representatives from Con-X, NGST and TPF science and engineering communities may attend if needed to help reach consensus on resolution plans for system-level cryocooler issues.

2.3 Demonstration Phase Delta PDR

The Demonstration Phase Delta PDR, to be held at the contractors site, will review the proposed disposition of action items / issues discussed at the Demonstration Phase Kick-off Meeting. The purpose is to confirm agreement between all parties that any changes planned or made in response to the Kick-off Meeting will improve the cryocoolers' design and/or applicability to OSS Astronomy and Physics Division missions.

2.4 Technical Interchange Meeting (TIM) #1

TIM #1 will examine and evaluate progress against plans, review major issues, problems, and resolution plans, relative to the Delta PDR and upcoming CDR

2.5 Critical Design Review (CDR)

The CDR, to be held at a NASA site, will occur after the EM cryocooler system detailed design has been completed, but prior to the start of hardware manufacturing or coding of software. The CDR will examine the compliance of the proposed design to the ACTDP requirements, highlighting any changes that have occurred since the Delta PDR. The CDR will confirm the readiness to begin hardware development by examining acquisition plans, fabrication plans / drawings, assembly procedures, and acceptance plans for all system elements. The aim is to provide confidence that the proposed design, and the planned manufacturing and test methods and procedures, will result in an acceptable product, with minimal development risk.

The Critical Design Review must address the following areas:

2.5.1 EM cryocooler system final design

The description of the final EM detailed design must include the following:

2.5.1.1 Final layout of components in the configuration in which the system will be tested with a discussion of the structural analysis performed and verification approach planned.

2.5.1.2 Final layout and schematics of the electronics that will be used to power and control the EM mechanical cryocooler in its test configuration. Identify components and functions that must be added or upgraded to support long-term life testing.

2.5.1.3 An analysis showing compliance with the electronic packaging structural/thermal requirements in APPENDIX A.

2.5.1.4 Final assembly drawings of major subassemblies.

2.5.1.5 Fabrication drawings.

2.5.1.6 Final interface geometries at the 6K and 18K coldtips, and at any intermediate temperature stages.

2.5.1.7 Heat sink interface specifications for the EM cryocooler system.

2.5.1.8 Thermodynamic performance, and a discussion of how it has been calculated. Any applicable test results shall be discussed.

2.5.1.9 Design assumptions, operational considerations, and discussion of design margins (mechanical, electrical, environmental, etc.).

2.5.1.10 A thorough analysis showing compliance with the End-of-Life (EOL) requirements in APPENDIX A. Identify the most critical components, and options for increasing life and reliability.

2.5.1.11 Vibration isolation, thermal isolation brackets for distributed plumbing, or any other thermal/mechanical details that will impact system cost or performance. The status and plans for measuring the self-induced vibration of the EM cryocooler vibration shall be provided.

2.5.1.12 Final mass and power budget for the EM cryocooler and flight electronics, and an update of the mass and power budget for a flight cryocooler system.

2.5.2 EM Electronics Design

Provide updates of the conceptual flight electronics design, including block diagrams, performance assumptions, identification of critical components, and any limitations on the location of the electronics relative to the cryocooler.

2.6 EM Analysis and Test Plan Pre-Test Review

The EM Test Plan must be approved by the ACTDP Manager prior to the start of formal testing of configuration items and/or subsystems. The EM Test Plan shall describe the cryocooler system characteristics to be verified by analysis, and measurement methodology including pass/fail criteria for each test. Discuss proposed instrumentation, and data acquisition / storage equipment to be used. The intent is to ensure that the test article hardware/software, test facility, personnel, and analysis / test procedures are ready for testing, data acquisition, reduction, and control including complete record keeping of all tests and their results.

The Pre-Test Review will examine:

- Design changes since CDR
- Status of non-conformances
- Test documentation (plans, procedures, waivers, pass/fail criteria)
- Facilities and personnel readiness
- Hardware and software configuration

2.7 Technical Interchange Meeting #2

TIM #2 will examine and evaluate progress / results, major issues, problems and resolution plans

2.8 Technical Interchange Meeting #3

TIM #3 will examine and evaluate progress / results, testing, major issues, problems and resolution plans

2.9 Technical Interchange Meeting #4

TIM #4 will examine and evaluate progress / results, testing, major issues, problems and resolution plans, and assess the potential for successful completion of the Demonstration Phase activity.

2.10 System Test Report

The System Test Report shall contain:
- A discussion of verification tests and analysis done
- As tested configuration information (drawings, schematics, etc.)
- Test data, results and analysis for each test conducted

2.11 Acceptance Data Package

The acceptance data package shall contain:
- As built configuration information (drawings, schematics, etc.)
- Verified test tools
- Outputs from all previous processes
- A statement of provisional acceptance (i.e. system readiness for additional testing)
- A transfer document (including a summary of acceptance test results)

2.12 Pre-Ship Review (PSR)

The PSR is conducted at the end of the system development process (design, built, test, evaluation). The PSR verifies the degree to which all system elements meet the ACTDP cryocooler specifications and requirements. It also verifies that testing has been completed with no unacceptable open issues, and verifies the readiness of the hardware and software system, and ground support equipment to be shipped to a NASA site. The PSR at a minimum, shall cover:
- Determination of completion of testing hardware and software
- Verification of system requirements
- Verification and documentation of final hardware and software configuration
- Identification and status of outstanding safety risks
- Disposition of waivers, deviations, open issues
- Results of compatibility testing of cryocooler and ground support equipment
- Results of end-to-end cryocooler system testing and verification
- Evaluation of the acceptance data packages

2.13 EM Cryocooler System

The contractor shall deliver to JPL or GSFC the ACTDP cryocooler system. This shall at a minimum include:

- The EM mechanical cryocooler and its brassboard electronics
- Other lab electronics needed for test / operation of the EM cryocooler system
- Ground support equipment and test setup (built under this contract)

2.14 FM Cryocooler Development Plan

The FM Cryocooler Development Plan shall describe the technical specifications and development plans, including a schedule and identification of long-lead items and timing, and management and cost plan, for delivering a FM cryocooler system.

ATTACHMENT E.4.b ACTDP CRYOCOOLER TECHNOLOGY DEVELOPMENT SAMPLE WORK BREAKDOWN STRUCTURE

1.0 Management
- 1.1. Task Management
- 1.2. Risk Management
- 1.3. Reserves

2.0 Product Assurance & Safety

3.0 Systems Engineering

4.0 EM Mechanical Cryocooler
- 4.1. Design
- 4.2. Build and Test

5.0 Brassboard Electronics for the EM Mechanical Cryocooler
- 5.1. Design
- 5.2. Build and Test

6.0 EM Electronics for the EM Mechanical Cryocooler
- 6.1. Design
- 6.2. Development Plan
- 6.3. Build and Test

7.0 Cryocooler System Integration & Test
- 7.1. Cryocooler System Integration
- 7.2. Cryocooler System Design and Verification Program (*refer to APPENDIX A*)
  - 7.2.1. Digital Communication and Software Functionality Test
  - 7.2.2. Thermal Vacuum Refrigeration Performance Test
  - 7.2.3. Cryocooler Temperature Control and Stability Test
  - 7.2.4. Electrical Power Interface and EMI Test
  - 7.2.5. Launch Vibration Test
  - 7.2.6. Self-Induced Vibration Test
  - 7.2.7. Cryocooler Leak Rate Test
  - 7.2.8. Cryocooler Life Analysis
  - 7.2.9. Cryocooler Structural Analysis and Verification
  - 7.2.10. Electronic Packaging Structural/Thermal Analysis

8.0 Ground Support Equipment

9.0 FM Cryocooler Development Plan

ATTACHMENT E.4.c ACTDP DEMONSTRATION PHASE COST PLAN INSTRUCTIONS

The cost plan shall provide sufficient information on the anticipated costs for all aspects of the cryocooler demonstration phase effort to enable a fair and reasonable assessment of the proposed total cost and funding requirements. Cost differs from "funding", which is defined in the Funding Profile section below. The total cost is the total amount of resources used for all activities including any NASA funding from sources other than the ACTDP and all non-NASA funded contributions. This includes direct and indirect costs that contribute to the effort regardless of funding sources. Clearly distinguish between the total cost, the cost to NASA, and the cost to the ACTDP. Provide a preliminary agreement or endorsement for "leveraged" NASA funding. The total cost shall include the full cost (including the assumptions used to develop the "full cost") of any civil service support to the activity, including technologies provided, project management staff, technical advisors, facilities, etc.

Direct costs that can be specifically related with the ACTDP Demonstration Phase activity include: (a) salaries and other benefits for employees who work directly on the task, (b) materials and supplies used directly in support of the task; (c) various costs associated with office space, equipment, facilities, and utilities that are used exclusively by the task; and (d) costs of goods or services received from other tasks or entities that are used to produce the ACTDP cryocooler.

Indirect costs include resources that are jointly or commonly used to produce two or more types of products but are not specifically identified with any of the products. Typical examples include labor overheads, material handling, cost of money, general administration, general research, and technical support, security, rent, employee health and recreation facilities, operating and maintenance costs for buildings, equipment, and utilities.

Describe the methods and assumptions by which the cost estimates are derived. Cost estimating procedures shall be based upon standard cost accounting principles and practices and shall be in accordance with the proposer's approved accounting system.

Costing of Federal Government elements of proposals shall follow the agency cost accounting standards for full cost. If no standards are in effect for the agency, then follow the Managerial Cost Accounting Standards for the Federal Government as recommended by the Federal Accounting Standards Advisory Board. NASA Centers may submit full cost proposals based on the instructions in the NASA Financial Management Manual, Section 9091-5, Cost Principles for Reimbursable Agreements.

All costs shall be in U.S. real year dollars. Real year dollars are current fiscal year (FY) dollars adjusted to account for inflation in future years. The inflation rate index provided in Table E.4-1 shall be used to calculate all real year dollar amounts unless an industry forward pricing rate is used. Where cost phasing is requested, the cost plan shall provide data by U.S. Government Fiscal Year (October 1 – September 30).

Table E.4-1, NASA New Start Inflation Rate Index

Fiscal Year	2002	2003	2004	2005	2006	2007	2008	2009
Inflation Rate	0.0%	2.8%	2.8%	2.8%	2.8%	2.8%	2.8%	2.8%
Cumulative Inflation Index	1.0	1.028	1.057	1.086	1.117	1.148	1.180	1.213

Provide a Demonstration Phase cost summary by WBS by fiscal year as shown in Table E.4-2.

Table E.4-2 Demonstration Phase Cost Summary by WBS

Demonstration Phase Cost Summary by WBS (All costs in Real Year Dollars)				
WBS / Cost Category Description	FY03	FY04	FY05	Total (RY$)
Total Direct Labor Cost	$	$	$	$
WBS 1.0 Management	$	$	$	$
WBS 2.0 Prod. Assur. & Safety	$	$	$	$
WBS 3.0 Systems Engineering	$	$	$	$
Etc.	$	$	$	$
Total Overhead	$	$	$	$
WBS # and Description	$	$	$	$
:	$	$	$	$
Total Direct Material & Equip. Costs	$	$	$	$
WBS # and Description	$	$	$	$
:	$	$	$	$
Total Subcontract Costs	$	$	$	$
WBS # and Description	$	$	$	$
:	$	$	$	$
Total Other Direct Costs	$	$	$	$
WBS # and Description	$	$	$	$
:	$	$	$	$
Total Indirect Costs	$	$	$	$
WBS # and Description	$	$	$	$
:	$	$	$	$
Total Reserves	$	$	$	$
WBS # and Description	$	$	$	$
:	$	$	$	$
Other Costs (Specify)	$	$	$	$
Fee	$	$	$	$
Total ACTDP Cost	$	$	$	$
Total Other Costs to NASA	$	$	$	$
Other (Specify)	$	$	$	$
Total Cost to NASA	$	$	$	$

Total Contributions by Other Organizations	$	$	$	$
Organization A:	$	$	$	$
WBS # and Description	$	$	$	$
Etc.	$	$	$	$
Organization B:	$	$	$	$
WBS # and Description	$	$	$	$
Etc.	$	$	$	$
Organization Z:	$	$	$	$
WBS # and Description	$	$	$	$
Etc.	$	$	$	$
Total Demonstration Phase Cost	$	$	$	$

The following information regarding categories of cost should be used in generating Table E.4-2:

a. Direct Labor Costs – List by labor category, with labor hours and rates for each. Provide actual salaries of all personnel and the percentage of time each individual will devote to the effort.

b. Overhead – Include indirect costs itemized by fiscal year. Usually this is in the form of a percentage of the direct labor costs.

c. Materials – Provide the total cost of the bill of materials including estimated cost of each major item (include lead time of critical items). Supporting detail for major vendors (exceeding $500,000.00) shall include WBS element, fiscal year, description, vendor name/address, quantity, and current/proposed unit prices. Material burden rates shall be documented.

d. Special Equipment – Include a list of special equipment with lead and/or development time.

e. Subcontracts – Supporting information shall be provided for all subcontracts exceeding $100,000.00. This detail shall include name/address, cost, fee/profit, and type of contract, basis of selection, and concise basis of estimate, and basis of selection. Include any baseline or supporting studies.

f. Other Direct Costs – Other direct costs (such as travel) shall be summarized by category and totals for each fiscal year. Regarding travel, provide an additional summary listing the estimated number of trips, destinations, duration, purpose, number of travelers, and anticipated dates.

g. General and Administrative (G&A) Expense – G&A expense includes the institution's general and executive offices and other miscellaneous expenses related to business.

h. Cost of Money (COM) – COM represents interest on borrowed funds invested in facilities.

i. Profit/Fee (if applicable) – Document the basis, rate, and amount of profit.

j. Other Costs – Costs not covered elsewhere

k. Escalation Factors – Identify the escalation factors used to determine real year dollars if different than Table E.4-1.

In addition to the summary of cost information, the following information shall be provided:

1. Summary of Cost Reserves and Margins – A summary of cost reserves and margins shall be identified by fiscal year and project element and the rationale for them discussed. The specific means by which integrated costs, schedule, and technical performance will be tracked and managed shall be explained. Management of the reserves and margins, including the management organization person responsible for managing the reserves, and when and how the reserves are to be released, shall be discussed. All funded schedule margins shall also be discussed.
2. Funding Profile – Provide a profile of required ACTDP funding by fiscal year. The funding profile is derived from the cost profile, which is the basis of the proposal. The funding for a given fiscal year is determined from the estimated costs in that year, less funding carried over from the previous fiscal year, plus the forward funding needed to cover the costs of the first month in the following fiscal year. Because of forward funding, costs will not equal funding in any given fiscal year. Total costs shall equal total funding at task completion.

ATTACHMENT E.4.d SUPPLEMENTAL INFORMATION

The following additional information is required to be supplied with the Technology Concept Definition Study Phase Final Report. This information shall be included as Appendices to the report.

1. Resumes – Provide resumes for all key personnel identified in the Demonstration Phase Management and Cost Plan. Include resume data on experience, which relates to the job these personnel will be doing for the proposed investigation.

2. Letters of Endorsement – Signed letters of endorsement shall be provided from the lead representative of all organizations participating in and critical to the demonstration phase activity. The information shall consist of, at a minimum, name of the item / support to be provided, scope of the work to be performed, name and location of supplier or subcontractor, proposed award schedule, deliverable items and delivery schedule, proposed performance assurance requirements, and contingency plans if a supplier or subcontractor fails to perform.

3. Statement(s) of Work – Provide a Demonstration Phase draft Statement of Work for all potential contracts (or other agreements) with NASA. Clearly define all proposed deliverables, potential requirements for Government facilities and/or Government services, and a proposed schedule.

4. Past Performance – Discuss relevant experience and past performance (successes and failures) of the major partners in meeting cost and schedule constraints in similar technology development activities within the last five years. Provide a description of each project, its relevance to the proposed technology subsystem experiment, cost and schedule performance, and points of contact (including addresses and phone numbers).

5. Copy of References – All citations given in the final Study Phase Report shall be included as part of an appendix of references, which includes the complete paper and/or a copy of relevant pages as appropriate from a book reference, and an easily understood abbreviation of the publication (e.g., library standard citation or AIAA format).

6. Acronyms List.